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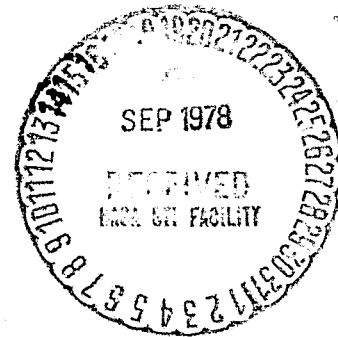
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SRB MATERIALS AND PROCESSES ASSESSMENT FROM LABORATORY AND OCEAN ENVIRONMENTAL TESTS

Materials and Processes Laboratory

June 1978

NASA



*George C. Marshall Space Flight Center
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SRB MATERIALS AND PROCESSES ASSESSMENT FROM LABORATORY AND OCEAN ENVIRONMENTAL TESTS

SUMMARY

This report covers the Materials and Processes Laboratory evaluation of Solid Rocket Boosters (SRB) and Solid Rocket Motors (SRM) candidate materials, both in-house and with ocean exposure tests at Panama City and Kennedy Space Center (KSC), Florida. The test hardware used was generally small scale laboratory samples of 158.75 mm (6.25 in.) by 177.8 mm (7.0 in.) typical size and the Integrated Test Bed (ITB). The ITB is a structure 3.048 m (10 ft) diameter by 2.438 m (8 ft) high and represents the SRB material combinations.

Early sample tests showed excellent seawater corrosion resistance for Inconel 718 and titanium 6Al-4V alloys. Considerable corrosion and biofouling occurred with bare 2219-T87 aluminum. Subsequent tests conclusively demonstrated that epoxy coatings (Cat-A-Lac epoxy primer No. 463-6-3 with 463-3-100 top coating) effectively prevent corrosion of 2219-T87 aluminum as long as the coating stays intact.

The second series of tests utilized samples of D6-AC steel, 4130 steel, Hy-140 steel, 18 Ni maraging steel, 2219-T87 aluminum, and 6061-T6 aluminum. Coatings for this series of samples were Rust-Oleum No. 9334 and Plasite No. 7140, both epoxy zinc-rich primers and one epoxy chromate primer, Cat-A-Lac No. 463-6-3. The top coat used was white epoxy. This second series of tests indicated that general surface corrosion can be controlled with a good paint system provided the ocean recovery is not delayed and the coating is not significantly damaged.

A third series of ocean tests were conducted to compare galvanize with zinc-rich paint for protecting steel to further evaluate epoxy chromate coating for 2219-T87 aluminum and determine the effectiveness of sealing to protect mechanically assembled joints. This test showed that galvanize alone would

not be a suitable protective coating. The zinc-rich paint system for steel once again demonstrated excellent protection. The epoxy chromate paint system offered good protection to the 2219-T87 aluminum alloy. These tests also indicated that fasteners could be used for structural assembly provided temperatures were not excessive, the structure not flexed excessively, and proper sealant and design were used. A series of long-term ocean exposure sealant-on-fastener tests confirmed the initial selection of PR 1422, a polysulfide type, and Dow Corning 93-076, a silicone, as the recommended sealers.

Concurrent with the assessment of materials and protective coatings from a corrosive standpoint, considerable investigative effort centered on an assessment of material biodegradation. Tests show that biodegradation is a valid area for consideration. 7075 aluminum is particularly susceptible to marine growth. The SRB should be lifted from the Banana River water as soon as possible in the recovery cycle. Biological growth in this location was determined to be more abundant than that exhibited in the selected ocean exposure site.

The ITB test was an ocean exposure of the prime candidate materials as a system. Included on the ITB were representative coatings, sealants, soft film preservative, and TPS (Marshall sprayable ablative, cork, and bonded silicone). A representative flotation system was installed, and a Thiokol pin retainer band similar to the SRM field splice joint protected the clevis joint. A final activity for the ITB was cleaning and refurbishment after the ocean and Banana River exposures.

The protective system utilized on the ITB appeared to provide good corrosion protection. Although some corrosion did occur in areas where the paint was damaged and under small blisters, the overall amount was not significant and was easily removed. The Thiokol design clevis joint seal did not totally exclude moisture. Rust was present in this joint when disassembled but was easily removed in the areas that had been previously oil coated. The ITB program further demonstrated the need for careful handling of the SRB. Considerable coating damage was caused by allowing lifting chains and slings to abrade against the side of the structure.

A final series of tests were conducted in the summer of 1977 to further assess the performance of the selected SRB materials. These tests were conducted on samples mounted to baskets and racks. The tests were conducted at the KSC Ocean Test Site approximately 2100 ft off shore in approximately 25 ft of water. The test at this site consisted of 7 day exposure, then returned to Banana River Test Site for a 1 day exposure. These tests substantiated previously established conclusions on biological growth, materials degradation, and the need for careful handling of the SRB.

I. INTRODUCTION

The Materials and Processes Laboratory at the Marshall Space Flight Center (MSFC) recognized early in the Shuttle program that material performance on a long-term basis would be critical to the success of the Shuttle and its goal of reusable components. The laboratory instituted in-house a comprehensive series of materials tests (Fig. 1) simulating expected environments for the refurbishable components of the propulsion system. These tests were subsequently expanded to include an ocean environment exposure of these laboratory type samples. Additionally, an Integrated Test Bed (ITB) of 3.048 m (10 ft) diameter by 2.438 m (8 ft) high was fabricated (Fig. 2) to scale up the size of the test in an ocean environment and to gain experience with application of the thermal protection system (TPS). The ITB also allowed cleaning and refurbishment with a test article which more nearly approximated the actual vehicle size than did laboratory samples. This report gives the results and an assessment of the series of ocean environmental tests that were conducted at Panama City and Kennedy Space Center (KSC), Florida, during the spring and summer of 1976 and 1977.

Chronology of testing was as follows:

- 1972 — Small Scale Bench Samples — First series of tests conducted in Gulf of Mexico at Panama to prepare for SRB materials selection
- 1973-1974 — Continued small scale bench sample test program in Gulf of Mexico
- 1975 — Small Scale Bench Samples — Material biogradation assessment — SRB recovery area in Atlantic Ocean
- 1976 — Small Scale Bench Samples — Continuation of 1975 test program and included testing in KSC test site 700 yd offshore.
- 1976 — ITB (Integrated Test Bed) test
- 1977 — Basket and rack test.

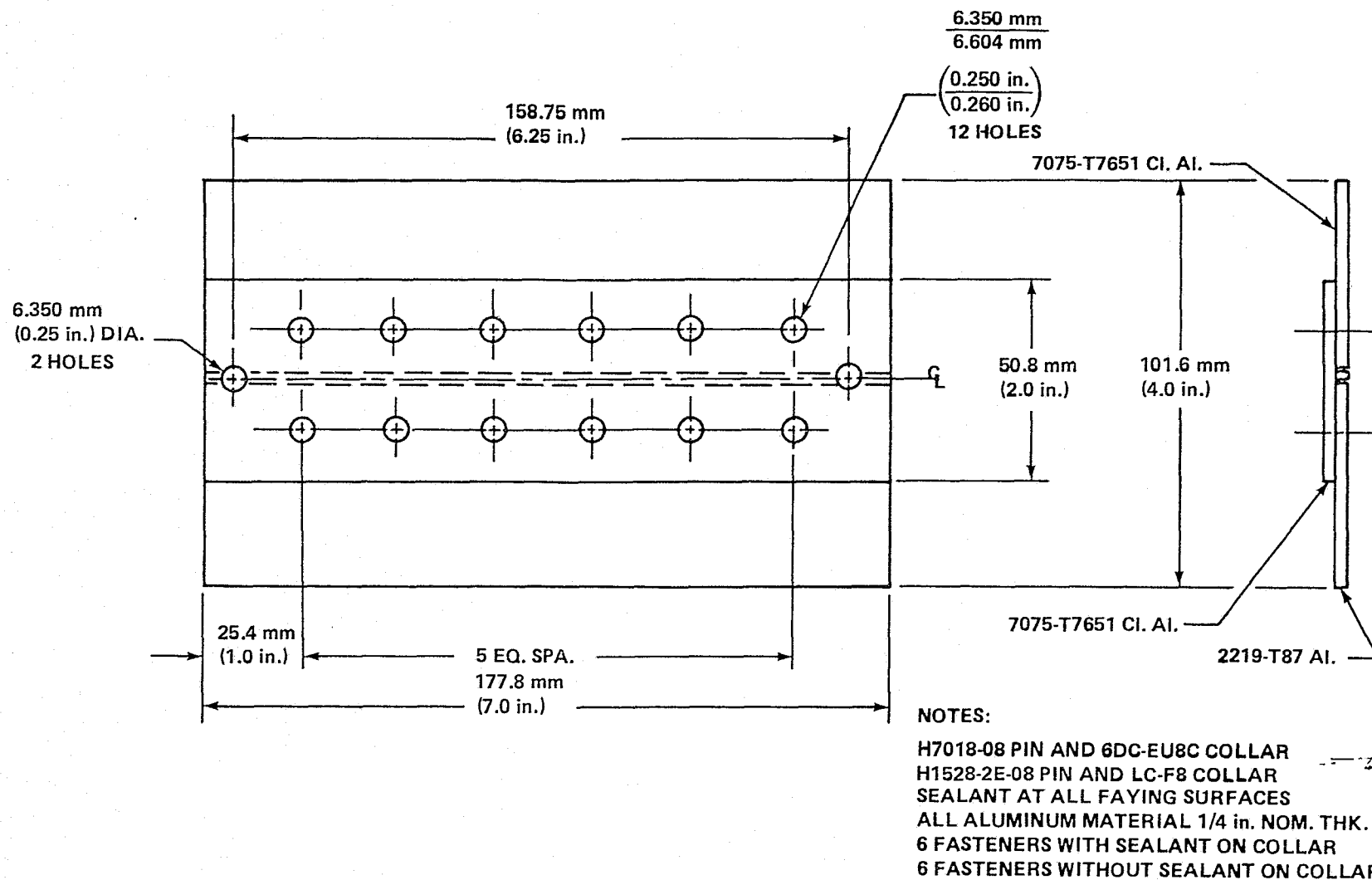


Figure 1. Materials testing and evaluation laboratory sample specimen configuration.

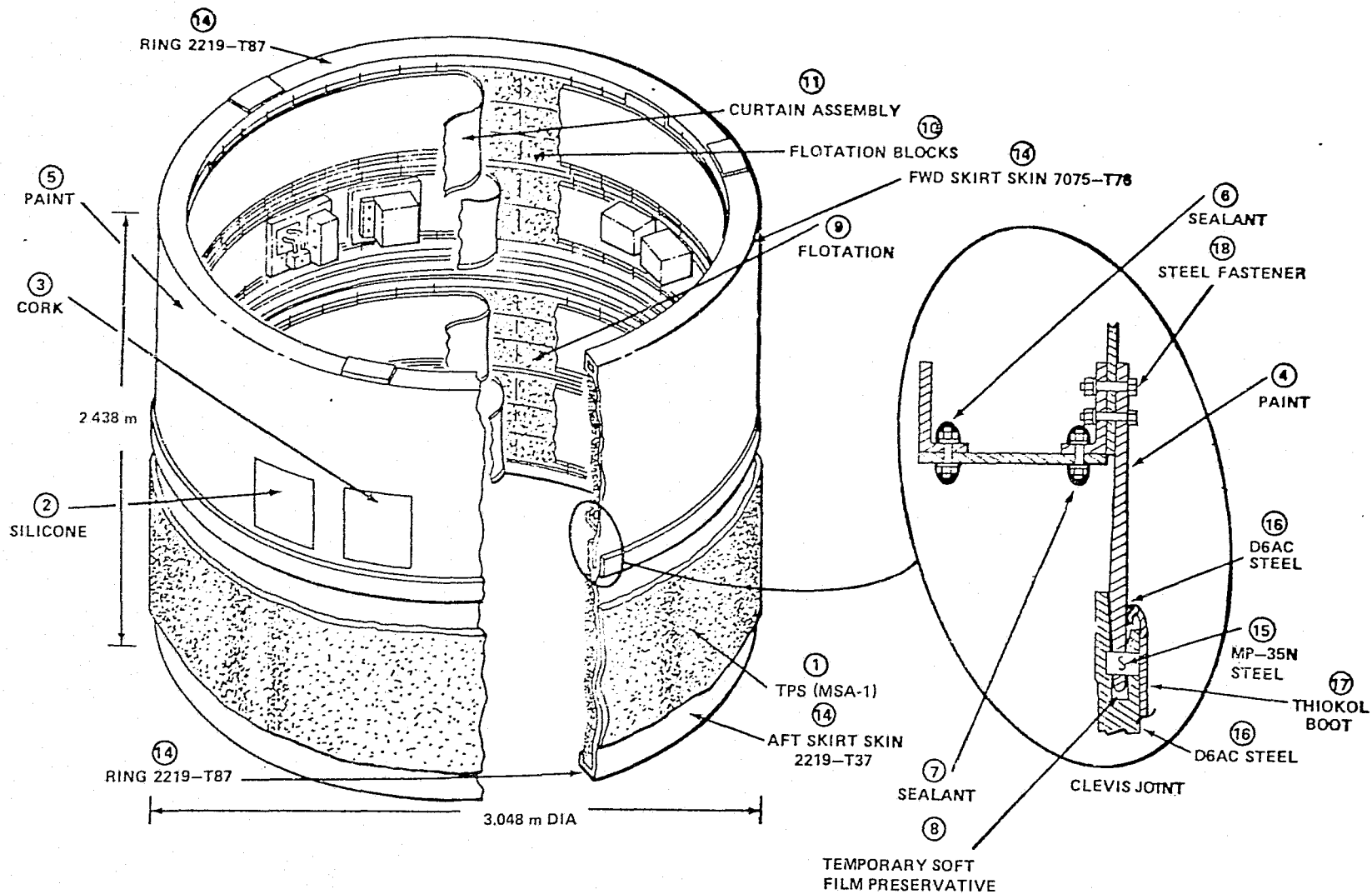


Figure 2. SRB Integrated Test Bed.

II. TEST HARDWARE

The structural materials and protective coatings initially specified for the Solid Rocket Booster (SRB) structures were selected on the basis of (a) published data on properties and performance, (b) a review of past experience with these and similar materials, and (c) laboratory and ocean exposure testing where published data were incomplete. In selecting these materials, however, it was recognized that performance data on materials repeatedly exposed to the SRB flight, recovery, and refurbishment cycle were not available. The ITB (Fig. 2) was directed at obtaining these performance data and establishing the refurbishment criteria and procedures.

The total program included the following four tasks:

- a. Materials testing of sealants and coatings (Table 1)
- b. TPS materials development and test (Table 2)
- c. Establishment of criteria for structural refurbishment and development of cleaning and refurbishment procedures (Table 3)
- d. Frustum flotation materials test and evaluation (Table 4).
- e. Nylon parachute materials test and evaluation (Table 5 and Fig. 7)
- f. TVC components test and evaluation (Table 6 and Figs. 8 and 9).

Laboratory samples (Fig. 1) were used in material screening studies and were tested in simulated seawater within the laboratory and seawater at selected ocean test sites. An ITB resembling the SRB frustum and incorporating all combinations of SRB materials was constructed and used in life cycle exposure, tow back, and refurbishment studies. This structure served as the primary vehicle for establishing refurbishment criteria and developing refurbishment techniques. Finally, the SRB Design Development Test and Evaluation (DDT&E) structures will be studied for real configuration verification of materials and processes selection and for refurbishment technique verification.

TABLE 1. ITB COATING PROTECTION

Item Number ^a	Identity	Material Cost as of June 78	Material Cost	Application Method	Remarks
4	Paint	Rust-Oleum 9334 — Primer Polyamide Zinc Rich Epoxy 9392 — Epoxy White	\$ 42.80/gal \$ 24.20/gal	Spray	Applied to D6AC Steel Material
5	Paint	Bostick-Finch 463-6-3 — Epoxy Primer 443-3-1 — Epoxy White	\$ 5.90/qt \$ 5.90/qt	Spray	Applied to Aluminum Material
6	Sealant	Product Research PR1422 — Liquid Polymer Polysulfide	\$ 16.44/qt	Manual	
7	Sealant	Dow Corning No. 1203 VM&P Naphtha — Primer No. 93-076 — Silicone	\$ 7.70/pt \$ 11.36/lb	Manual	
8	Temporary Soft Film Preserva- tive	Braycote No. 137 MIL-C-16173, Type II	\$ 4.72/gal	Brush	

a. From Figure 2.

TABLE 2. ITB THERMAL PROTECTION SYSTEM

Item Number ^a	Identity	Material	Material Cost	Application Method	Remarks
1	MSA-1 24-50P ^b		\$ 1.00/ft ² @ 1/4 in. thick	Automatic Spray	Base Coat 7344 Adhesive
2	PD200	GE Silicone	\$ 36.00/ft ² @ 1/4 in. thick	Manual — Bond	Base Coat RTV-60 Adhesive
3	P-50	Cork Composition Phenolic Binder	\$ 1.75/ft ² @ 1/4 in. thick	Manual — Bond	Base Coat RTV-60 Adhesive

a. From Figure 2.

b. MSA-1 Components — Phenolic Microballoons

Glass Eccospheres

7344 Resin

7119 Catalyst

Bentone 27

Ethyl Alcohol

1.585 mm (1/16 in.) Long Mill Fibers

6.35 mm (1/4 in.) Long Chopped Fibers

Methylene Chloride

Perchloroethylene

TABLE 3. STRUCTURAL MATERIALS

Item Number ^a	Identity	Material	Material Cost	Application Method	Remarks
12	Sling Assembly	Mild Steel	\$ 1325.00		Purchased Item — for Lifting
13	Safety Hoist Rings	Mild Steel	\$ 307.00		Purchased Item — for Lifting
14	Forward Skirt Skins	Aluminum 7075-T6	\$ 0.85/lb	Welding and Bolting	
	Plate, Channel, Angle	Aluminum 2219-T37	\$ 1.25/lb	Welding and Bolting	
	Aft Skirt Skin	Aluminum 2219-T87	\$ 1.25/lb	Welding and Bolting	
15	Pins	Steel MP35N	\$ 25.00 ea.	Manual Insertion	Surplus Titan — Assembly Qty. 120
16	Clevis Joint	Steel D6AC	\$ 1.62/lb	Bolted	Surplus Titan — Assembly Qty. 120

TABLE 3. (Concluded)

Item Number ^a	Identity	Material	Material Cost	Application Method	Remarks
17	Thiokol Boot	Rubber		Epoxy Glue Cure 24 h @100°F	Purchased Item — This Cost Included Thiokol Installation at MSFC
18	Fasteners	Cres Steel	Average Cost: Bolt — \$ 5-\$ 12 Washer — \$ 0.03- \$ 0.50 ea. Nut — \$ 0.12- \$ 0.50 ea.	Manual	Torque to Specifications

a. From Figure 2.

TABLE 4. ITB Flotation^a

Item Number ^b	Identity	Material	Material Cost	Application Method	Remarks
9	Foam	Polystrene No. 1	\$ 1.12/ft ³	Mechanical Lock and Bond	Coat with Latex Paint, Partial Breakup after Water Impact (10 cycles)
	Foam	Polystrene No. 2	\$ 2.00/ft ³	Mechanical Lock and Bond	Coated with Latex Paint, No. 1 Candidate Material
10	Foam	Polystrene CPR 630A/B	\$ 0.75 lb lqd		Pour in Mold Configuration, Failed Vacuum Exposure Test
11	Curtain and Ties	Nylon	\$ 3.75/yd ² Estimated	Laced	For Holding Foam Blocks in Position
Flotation Panel (July 1977 Test Program)					
	Expanded Bead	Polystrene 1 lb/ft ³	\$ 1.12/ft ³	Fitted Removable Blocks	Coated with Latex Paint, Partial Breakup after Water Impact (10 cycles)

TABLE 4. (Concluded)

Item Number ^b	Identity	Material	Material Cost	Application Method	Remarks
	Expanded Bead	Polystrene 2 lb/ft ³	\$ 2.00/ft ³	Fitted Removable Blocks	Coated with Latex Paint, No. 1 Candidate Material
	Curtain and ties	Dacron	\$ 2.50/yd ²	Laced	Low Elongation — No. 1 Candidate Material

- a. This flotation configuration was not exactly as shown in Figure 2 because final adjustment was required to make the ITB float in the "log mode" with approximately 20 percent above the water (Figs. 3 through 6).
- b. From Figure 2.

TABLE 5. NYLON PARACHUTE MATERIAL

Sample No.	Quantity	Identity	Specification	Application
EH 33-1A	3	Type II, 1 in. Wide, 4000 lb Breaking Strength	Mil-W-27657	Reefing and Suspension Lines, Main
EH 33-8A	3	Type XIX, 1 3/4 in. Wide, 10 000 lb Breaking Strength	Mil-W-4088	Radial Reinforcement, Drogue Vent and Skirt Bands, Main Riser
EH 33-9A	3	Type XXII, 1 1/8 in. Wide, 12 000 lb Breaking Strength	Mil-W-4088	Suspension Line, Drogue
EH 33-10A	3	Type XXVI, 1 3/4 in. Wide, 15 000 lb Breaking Strength	Mil-W-4088	Skirt Band, Drogue
EH 33-4	3	Type V, Class C, 2 in. Wide, 300 lb Breaking Strength	Mil-T-5608	Radial, Main
EH 33-6	3	Type II, Class E, 2 in. Wide, 1000 lb Breaking Strength	Mil-T-5608	Radial, Main
EH 33-8	3	Type V, 9/16 in. Wide, 500 lb Breaking Strength	Mil-T-5038	Vertical, Drogue, Main
EH 33-3	3	Type V, 2 in. Wide, 1500 lb Breaking Strength	Mil-W-83144	Horizontal, Drogue, Main

TABLE 6. SRB HARDWARE

Sample No.	Quantity	Identity	Application
1	1	Fluid Manifold Assembly, TVC System	Collector and Distributor of Subsystem Hydraulic Fluid, having Line Connection Provisions to Interface with Hydraulic Reservoir, Hydraulic Pump, Case Drain, Hydraulic Actuators and Panel Mounted Service Connectors.
1	1	Auxiliary Power Unit, TVC System	Provides Shaft Power to Drive the Hydraulic Pump of the SRB/TVC Subsystem.

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Figure 3. ITB off-loading from transporter at KSC.

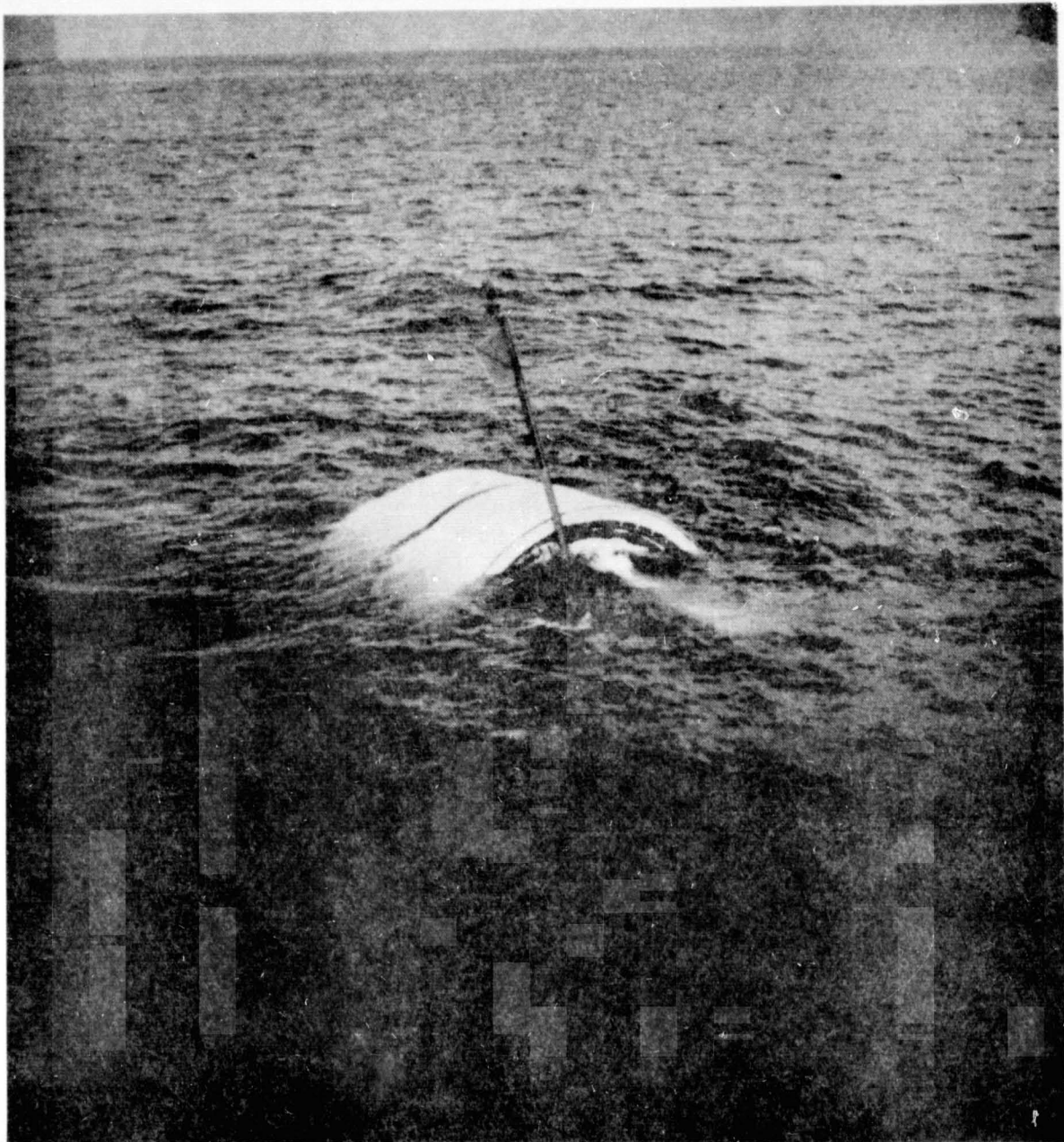


Figure 4. ITB ocean testing.

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Figure 5. ITB retrieval from ocean test site.

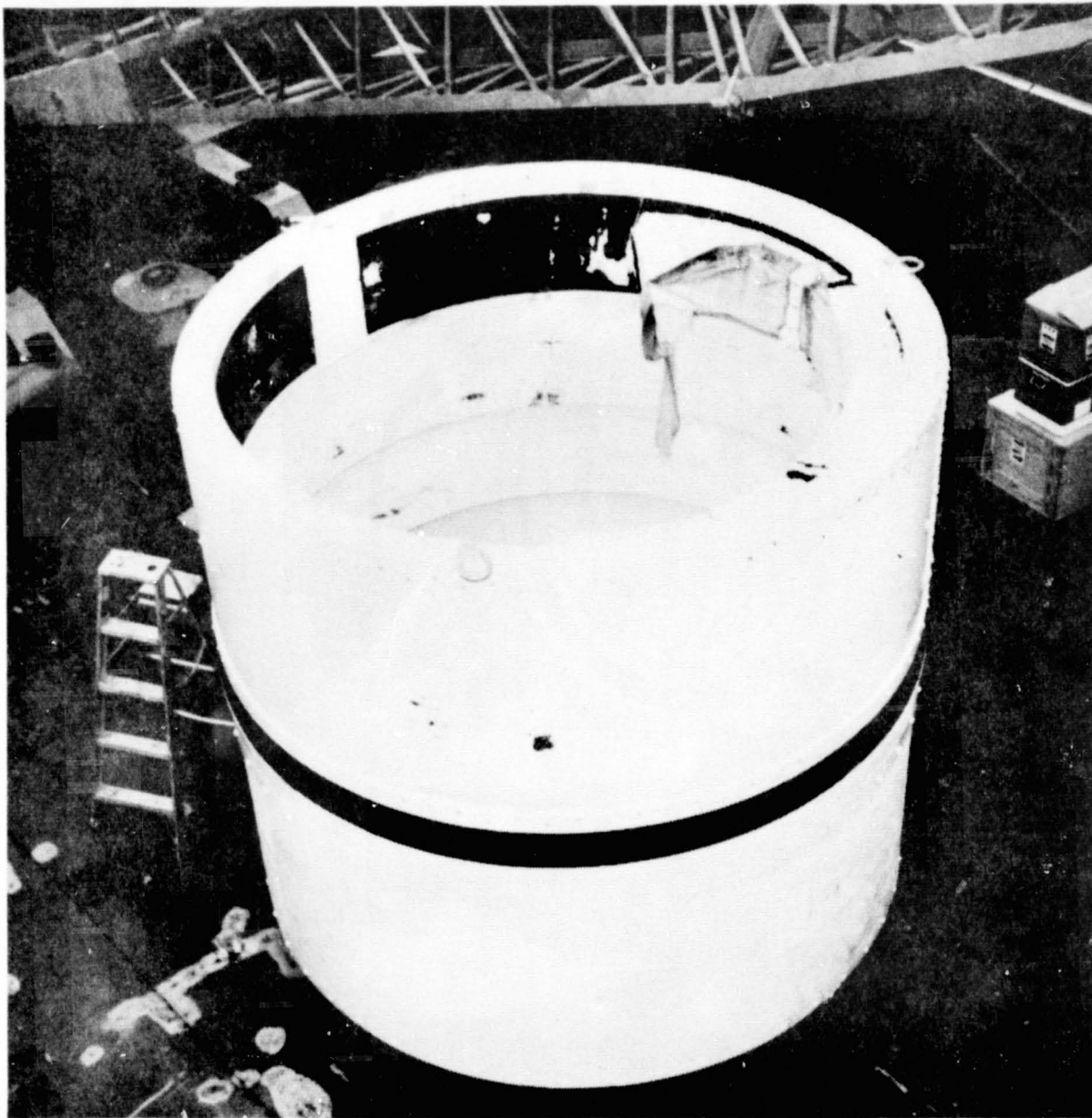
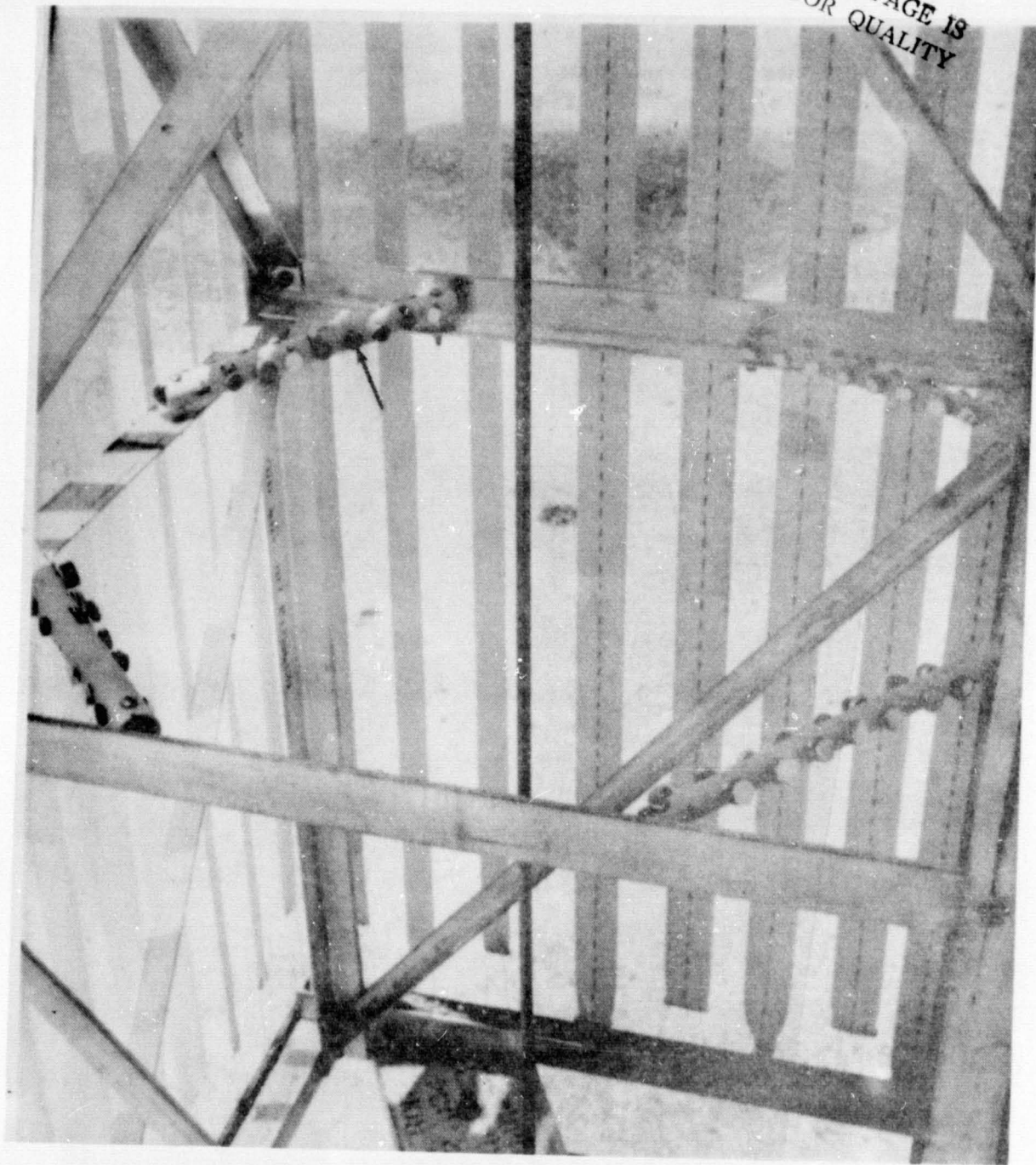


Figure 6. ITB aboard recovery ship.



Note: Scanning Electron Microscope (SEM) buttons (arrow).

Figure 7. Nylon parachute materials.

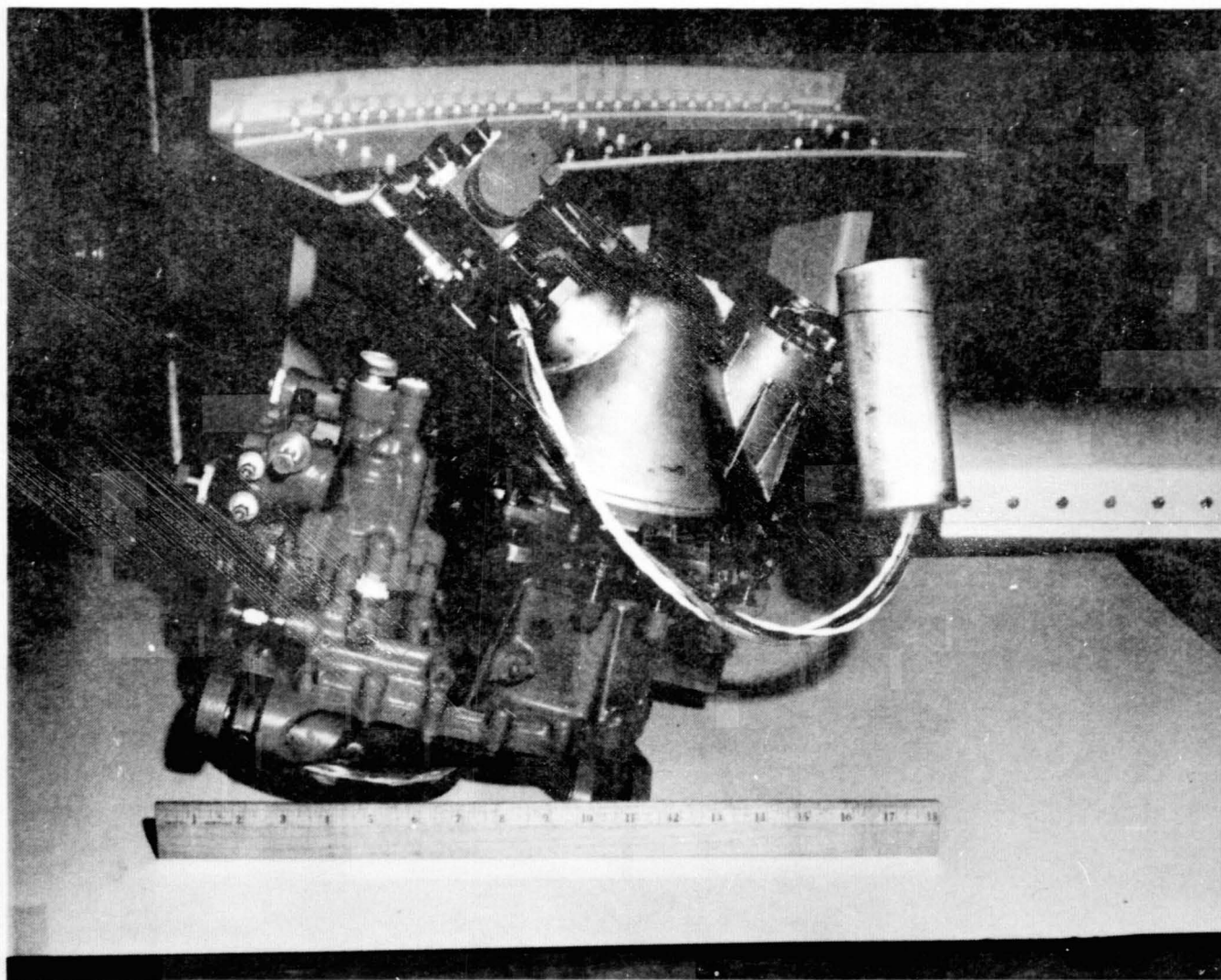


Figure 8. Auxiliary power unit.

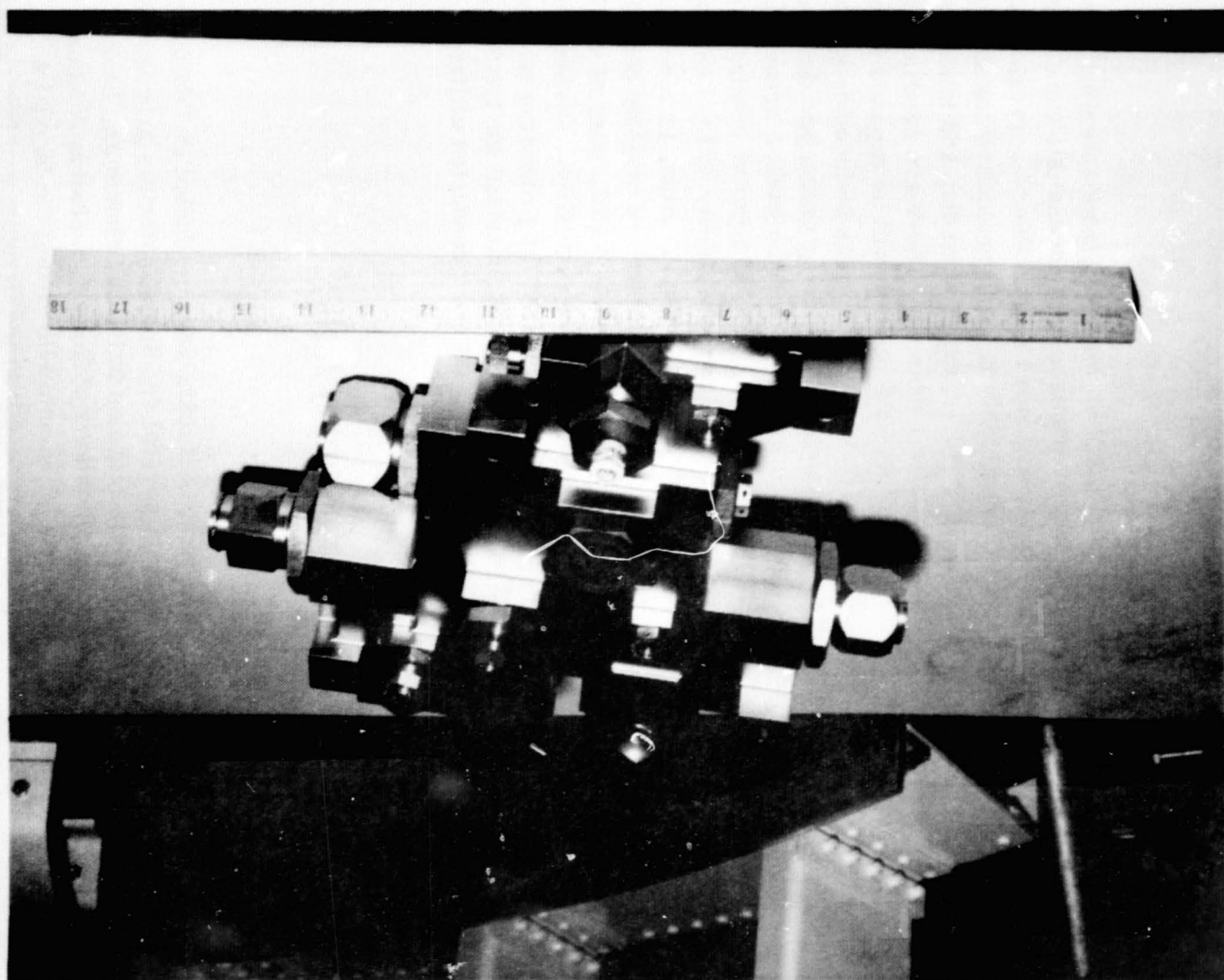


Figure 9. Fluid manifold assembly.

III. EVALUATION OF PAINT COATINGS AND SEALANTS

A. Introduction

General corrosion presents a problem for many materials which are exposed to seawater. Whenever design requirements necessitate the use of high strength materials which, in general, are more susceptible to corrosion degradation, serious attack can occur unless highly reliable protective coatings are utilized. The recovery method of the SRB — seawater landing and towing to port — can create very serious corrosion problems. There are several distinct environments to which the various parts of the booster will be exposed in the ocean recovery operation. Specifically, the environments include the seacoast atmosphere prior to launch, elevated temperature during ascent and descent, seawater during recovery and towback operations, and the harbor water prior to removal at dock site. In marine environments, several types of coatings are available which provide very good protection; however, many will not withstand the elevated temperatures expected during booster flight. Also, in considering the type of protective coating to be used, many other factors must be considered such as thickness of coating for maximum protection (weight), ease of application to large structures, abrasion resistance, and repairability. Consequently, as a result of the numerous requirements demanded of the protective coating, several studies were conducted on potential materials proposed for the SRB. As the design became more firm, additional tests were conducted utilizing typical materials and assemblies.

B. Preliminary Tests

1. First Tests in Gulf of Mexico.

a. Discussion. The first Gulf tests were conducted in February 1972. Samples were prepared from several candidate materials proposed for the Shuttle booster. These materials included 2219-T87 aluminum, Inconel 718, and Titanium 6Al-4V. Several combinations of finishes including Alodine, anodize, and paint were used on the aluminum alloy while the Inconel and titanium were left bare. Couples of aluminum to the titanium and Inconel materials were assembled using stainless steel fasteners to determine the galvanic effects when exposed to the seawater. The samples were exposed 2 miles

offshore at Panama City, Florida, in the harbor area at St. Andrews Bay bridge and in-house in a synthetic seawater solution. All exposures were for 7 days (Fig. 10).

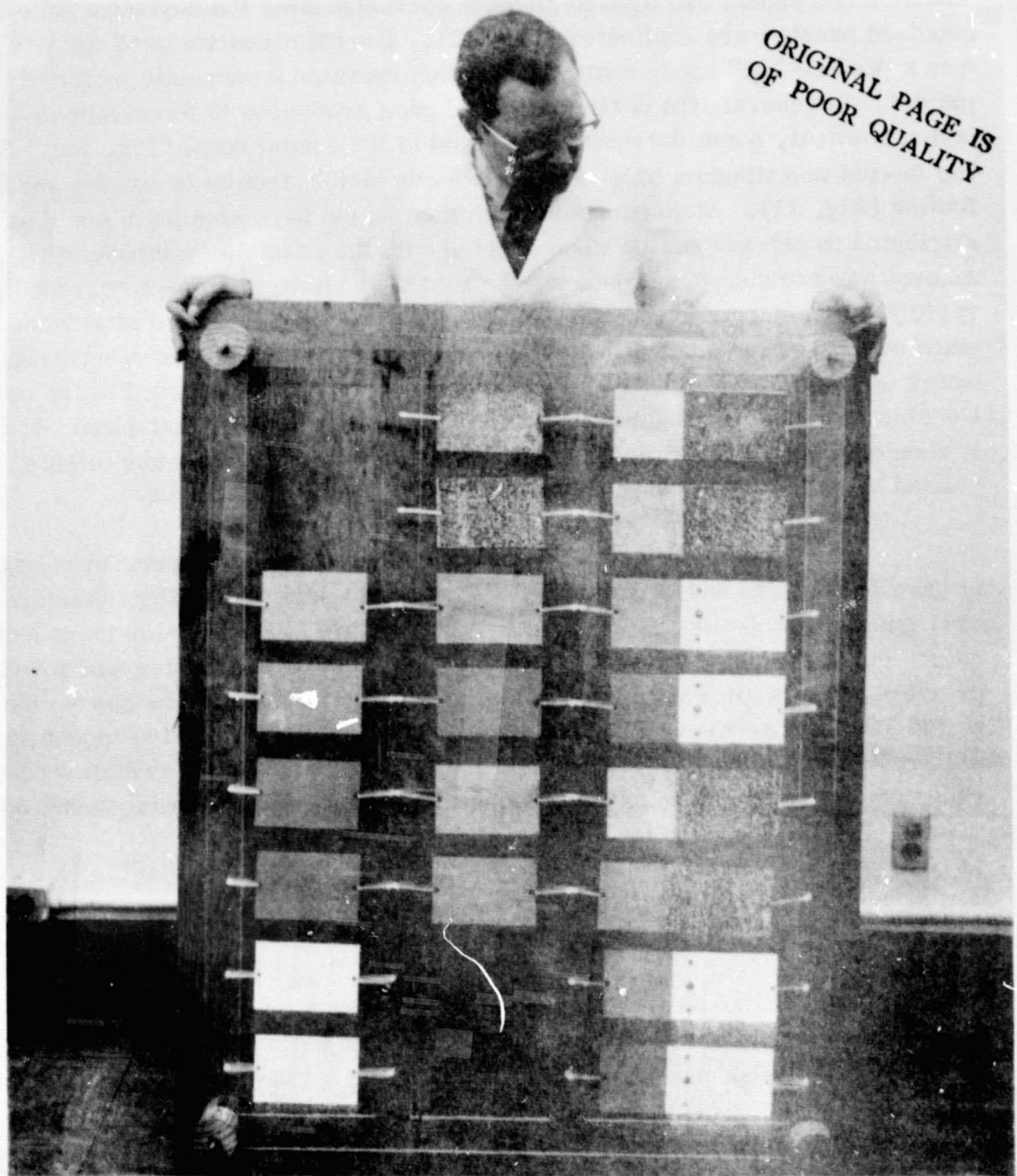


Figure 10. First Gulf of Mexico test — panels exposed in the bay for 7 days.

b. Results. Results of this test showed heavy corrosive attack and marine growth on the bare 2219 aluminum alloy exposed to both ocean and bay environments, with the heaviest being on samples exposed in the bay (Fig. 11). The alodined panels had light to medium corrosion over the surfaces while the anodized panels were unaffected (Fig. 12). The paint coating used for this test was a "Cat-A-Lac" epoxy coating which incorporated a chromate inhibited primer. In general, the coating afforded good protection to the aluminum surfaces; however, some corrosion was noted in the scribe mark (Fig. 12). Both the Inconel and titanium bare alloys were completely free of corrosion and biofouling (Fig. 11). Although some corrosion on the bare aluminum could be attributed to galvanic action when coupled with the titanium or Inconel 718, the amount was not significant because the rest of the bare aluminum corroded so rapidly. No evidence of galvanic action was noted on the painted aluminum when coupled to the other alloys. The samples exposed to the synthetic seawater in-house were considerably less affected than those exposed to the ocean. Considerably less corrosion was noted on the bare aluminum samples. Also, it should be noted that synthetic seawater tests cannot evaluate any effects caused by biofouling because of the absence of marine organisms.

c. Conclusions. This test showed the excellent corrosion resistance of bare Inconel 718 and Titanium 6Al-4V alloys to seawater. The considerable corrosion and biofouling which occurred on the bare 2219-T87 aluminum indicated, not surprisingly, that a coating system must be used which will provide protection if this alloy is to be used in the sea environment. The epoxy coating tested (Cat-A-Lac Epoxy Primer No. 463-6-3 with No. 463-3-100 topcoating) did provide this protection. The in-house test indicated that a synthetic seawater exposure did not result in as severe degradation as occurred in the ocean environment.

2. Second Gulf of Mexico Test.

a. Discussion. The second Gulf test was made to determine the corrosive effects of seawater on several candidate Solid Rocket Motor (SRM) case and attachment materials and to continue the evaluation of protective coating systems. The alloys selected for the study included D6AC steel, 4130 steel, HY-140 steel, 18 Ni Maraging steel, 2219-T87 aluminum, and 6061-T6 aluminum. The protective coatings used were selected after considerable literature search and consultations with industry and Naval organizations. Requirements for the coatings included outstanding corrosion protection in seawater, resistance to elevated temperatures for short periods, ease of application and repair, abrasion

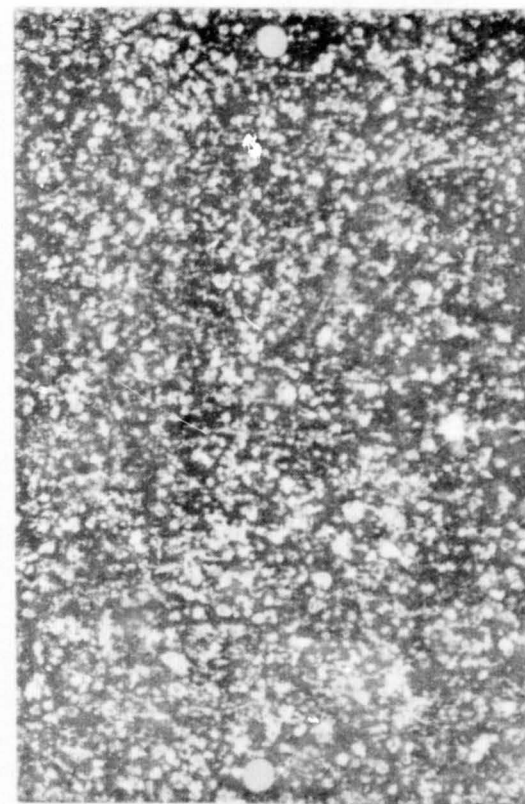
7 DAY BAY EXPOSURE (Uncoated Panels)



A. INCONEL 718



B. Ti-6Al-4V



C. 2219 ALUMINUM

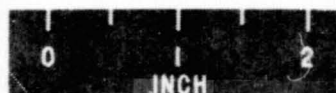
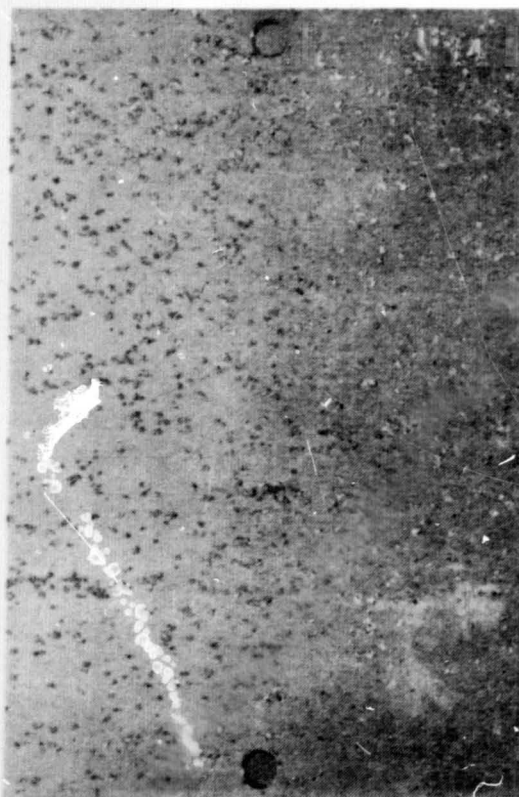


Figure 11. First Gulf of Mexico test — uncoated panels exposed in the bay for 7 day

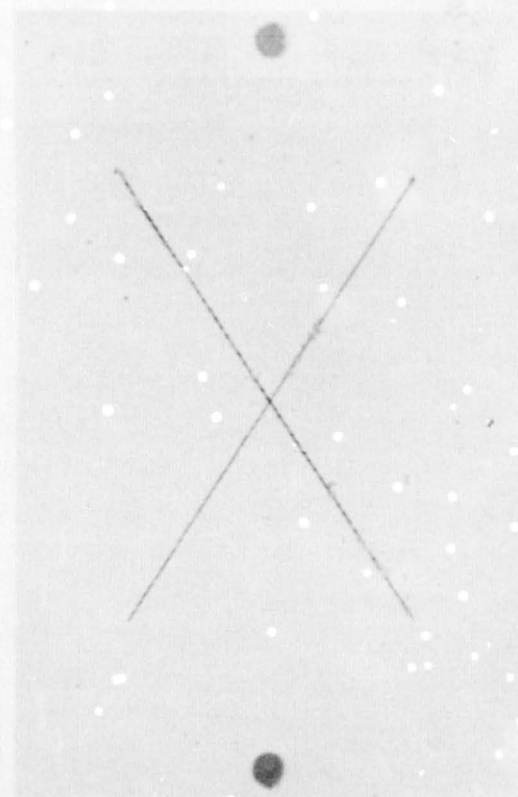
2219 ALUMINUM COATED PANELS (Bay Exposure)



ALODINE



SULPHURIC ACID ANODIZE



ALODINE + EPOXY
PRIMER & TOP COAT

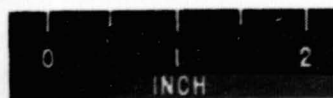


Figure 12. First Gulf of Mexico test — coated panels exposed in the bay for 7 days.

resistance, and durability. The coatings selected consisted of two sacrificial type epoxy zinc-rich primers (Rust-Oleum No. 9334 and Plasite No. 7140) and one epoxy chromate primer (Cat-A-Lac No. 463-6-3). The topcoats were all white epoxy type. Two sets of specimens were exposed in the Gulf 12 miles out from Panama City. One set of specimens was exposed for 24 h and the other for 72 h (Fig. 13).

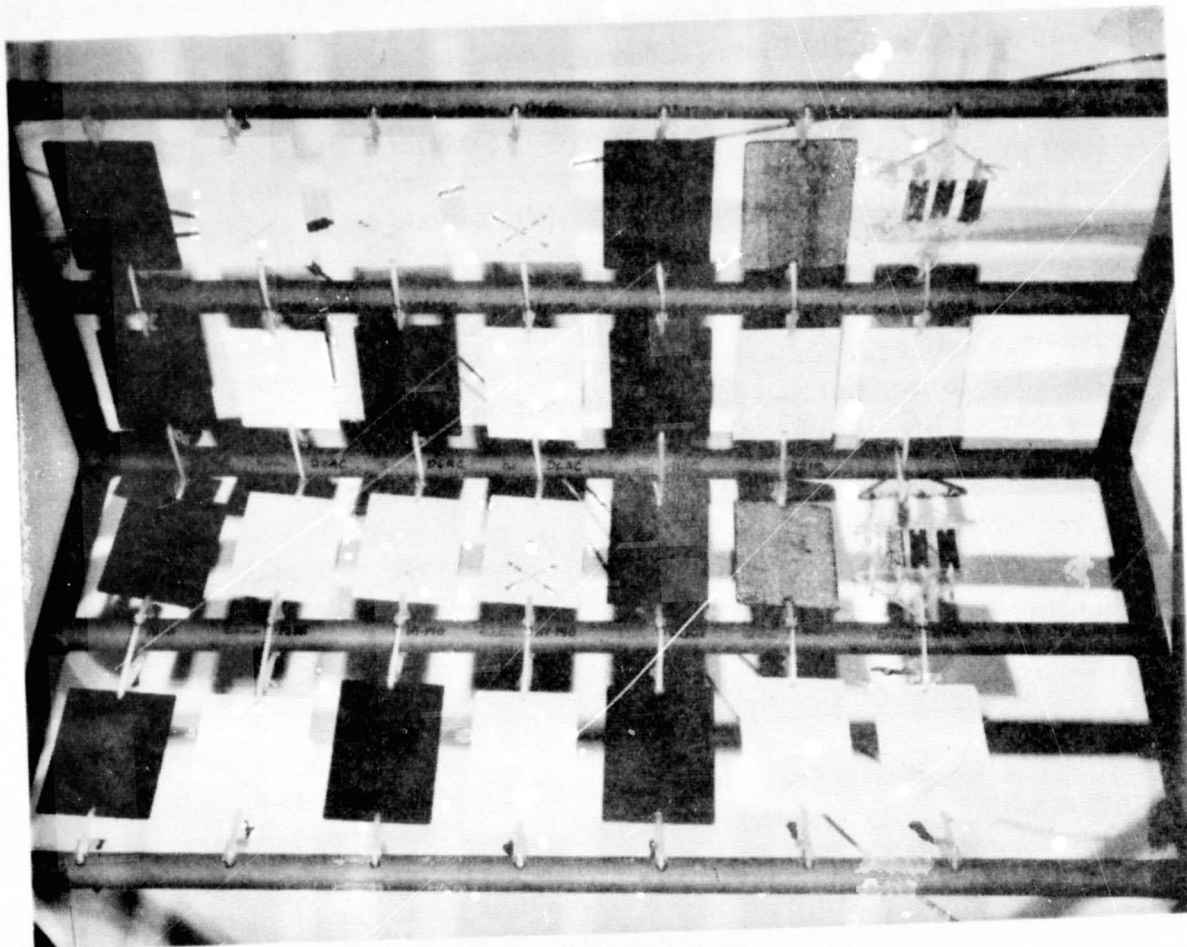


Figure 13. Second Gulf of Mexico test — panels exposed for 72 h 12 miles offshore.

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b. Results. All of the unpainted steel samples developed a light, irregular pattern of rust coating over most of the surfaces within a relatively short time. This rust coating did not increase significantly during the 72 h test, and there was no measurable pitting on the bare materials. The bare 6061-T6 aluminum turned dull grey after 24 h and darkened even more by 72 h. Only a very few light white spots of corrosion were evident. In contrast, the bare 2219-T87 had darkened and a light white coating of corrosion was present after 24 h. At the end of 72 h, the corrosion had increased considerably and pitting depth was found to be 0.1017 mm (0.004 in.). The coatings used in this test provided corrosion protection to the surfaces; however, one coating was somewhat superior to the other two coatings in providing protection to the scribed areas of the steel panels. This coating (Rust-Oleum) provided complete protection to all test panels except one, and this panel only had one small pinpoint of rust in the scribe mark. The other coatings allowed some slight rusting in the scribe. The deepest attack in the scribed areas was 0.019 mm (0.00075 in.) and was found on the panel with a chromated epoxy primer. The other two systems used an epoxy zinc-rich primer. The epoxy chromate (Cat-A-Lac) system provided complete protection to the 6061 and 2219 aluminum alloys. It was noted that considerably less marine life was observed initially on these panels than had been found on the panels exposed in an estuarine location during the first Gulf test.

c. Conclusion. In summary, these tests indicated that general surface corrosion can be controlled with a good paint system, provided the ocean recovery is not delayed and if the coating is not significantly damaged.

3. Third Gulf of Mexico Test.

a. Discussion. The third Gulf test was conducted to compare galvanize with zinc-rich paint for protecting steel, to further evaluate the epoxy chromate coating on 2219-T87 aluminum, to determine the effectiveness of sealing and protecting mechanically assembled joints, and to determine the effects of multiflight exposure to seawater. The materials evaluated were HY-140 steel (the leading steel candidate at the time for the aft skirt) and 2219-T87 aluminum alloy. The protective coatings used on the steel included the following: (1) galvanize, (2) galvanize and painted with Rust-Oleum zinc-rich epoxy No. 9334/No. 9392 topcoat, and (3) painted with Rust-Oleum No. 9334/No. 9392 topcoat. The coating used on the aluminum was a Cat-A-Lac epoxy chromate system, No. 463-6-3 primer and No. 463-3-100 white topcoat. Test specimens were fabricated by assembling two 177.8 mm (2.5 x 7.0 in.) plates using six Hi-Lok fasteners. The pins were A286 stainless steel and the collars were 2024-T6 aluminum (the aluminum collars were substituted for stainless steel

by mistake during fabrication). The steel panels with paint only were assembled with a silicone sealant (Dow Corning 731) applied to the faying surfaces, bolt holes, and over the fastener head and collar. This sealant was recommended because of the potential 148.9 to 260°C (300 to 500°F) temperature expected during booster flight. Four sets of samples were prepared. Two sets were exposed for 5 and 100 days in the Gulf (12 miles offshore) while two similar sets were exposed in-house in an alternate immersion tester with a 3.5 percent salt solution, also for 5 and 100 days. The 100 day in-house samples were subjected to a temperature of 300°F and flexed in a tensile machine every 5 days to simulate multiflight characteristics.

b. Results. Results of this test showed that after 5 days white corrosion covered the galvanized specimens (Fig. 14). The in-house specimens had considerably more corrosion products than the seawater specimens. The pH of the salt bath had risen due to the zinc depletion and the higher pH solution contributed to the aggressiveness of the salt bath. All painted panels were relatively unchanged by the 5 day in-house exposure and only minor changes were noted on the panels exposed in the Gulf (Fig. 15). One or two steel panels had light rust discoloration at the scribe mark which readily wiped off. One or two of the panels received some mechanical damage due to rack failure. Only a small amount of biological growth was present on the samples exposed in the Gulf, and this was readily removed.

After 100 days exposure in the Gulf, considerable biological growth had accumulated over all samples; however, when removed, very little deterioration on the painted panels was noted (Fig. 16). The marine growth was very tenacious, but was removed by scrubbing with a detergent solution. Light attack was noted in the scribe marks of the painted panels and also at the edges of some fasteners. There was no corrosion noted on the faying surfaces or in the holes of the steel panels which had been painted and assembled with the silicone sealant (Fig. 17). Some light corrosion was noted in these areas on aluminum panels without the sealant (Fig. 18). Light to medium corrosion had occurred on the galvanized panels but the steel was protected. Some galvanic corrosion was noted on the aluminum collars of the fastener assemblies. Similar results were noted on the 100 day in-house salt exposure, except for the marine growth and a much heavier attack on the bare galvanize. The bare galvanized panels were removed from test after 25 days.

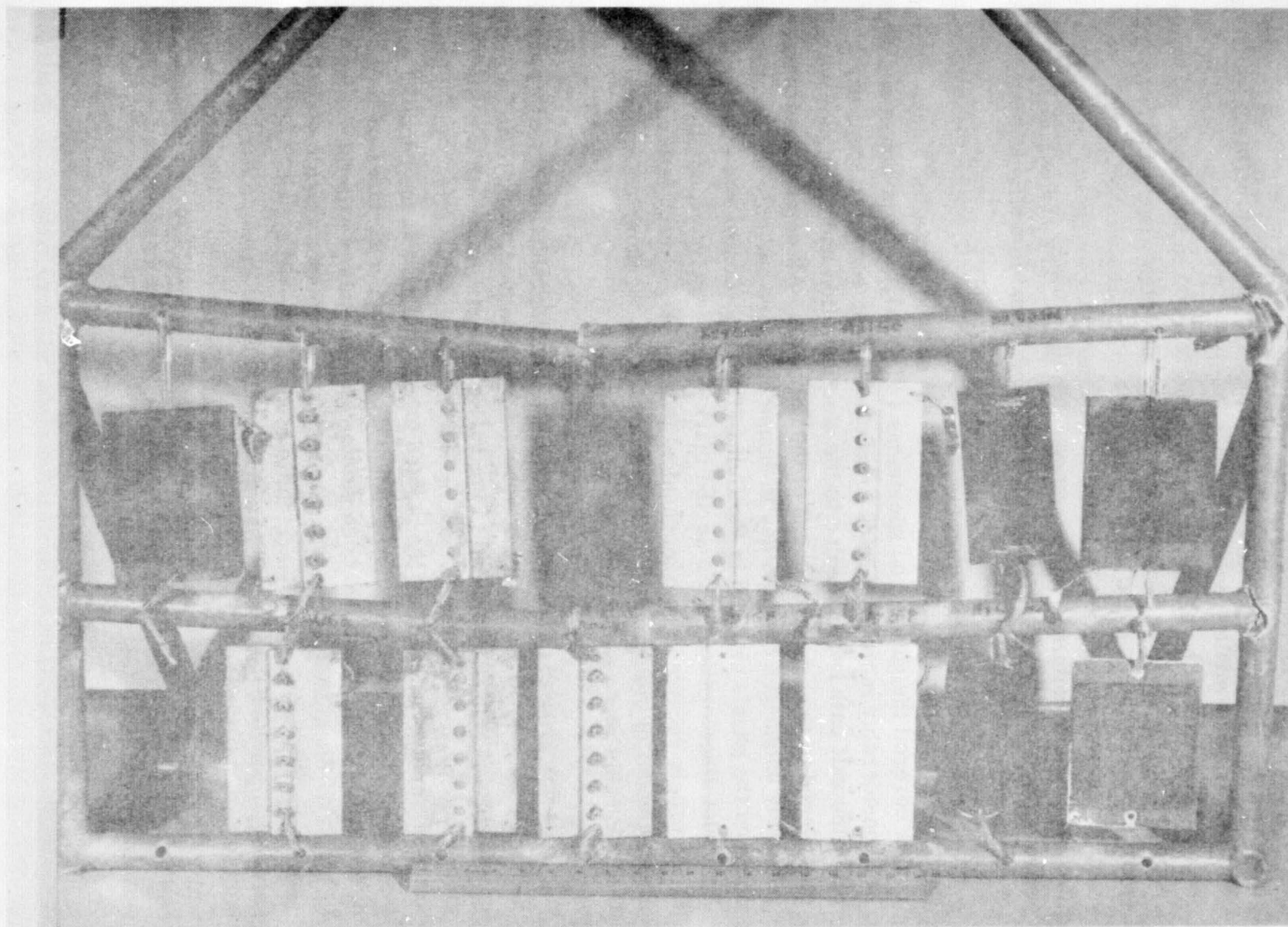


Figure 14. Third Gulf of Mexico test — galvanized panels exposed for 5 days 12 miles offshore.

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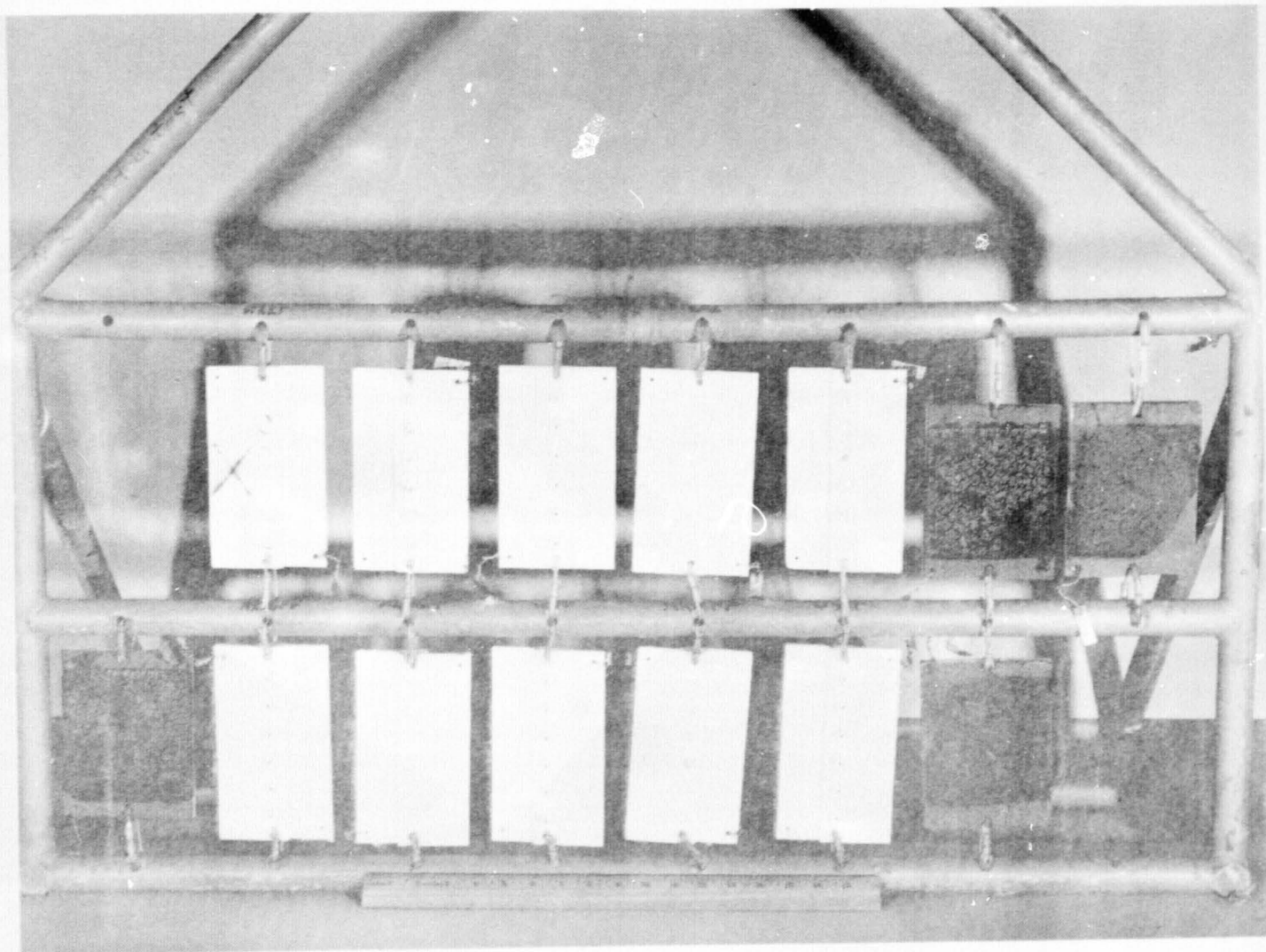


Figure 15. Third Gulf of Mexico test — painted panels exposed for 5 days 12 miles offshore.

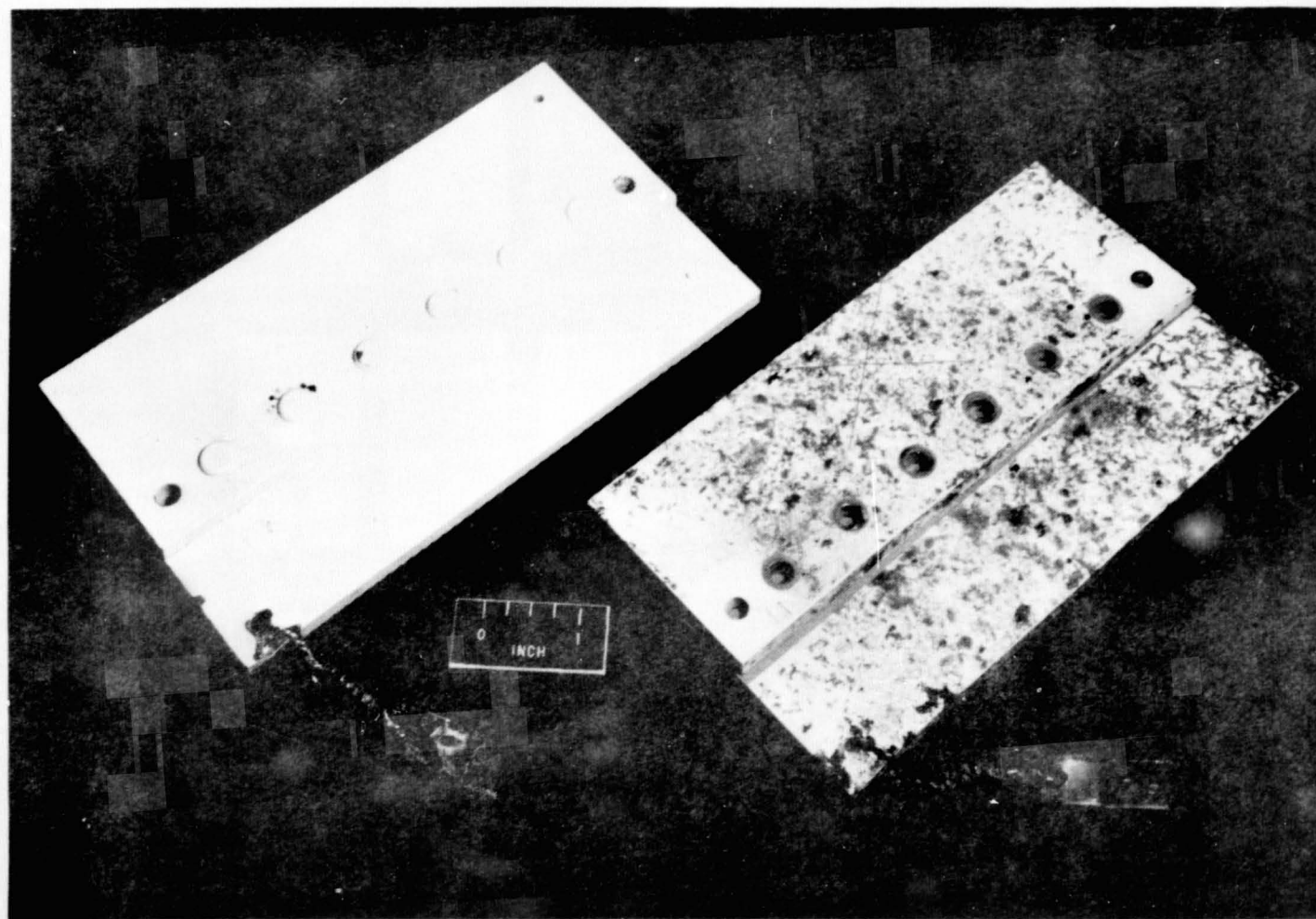


Figure 16. Third Gulf of Mexico test — aluminum panels before and after cleaning — 100 days ocean exposure.

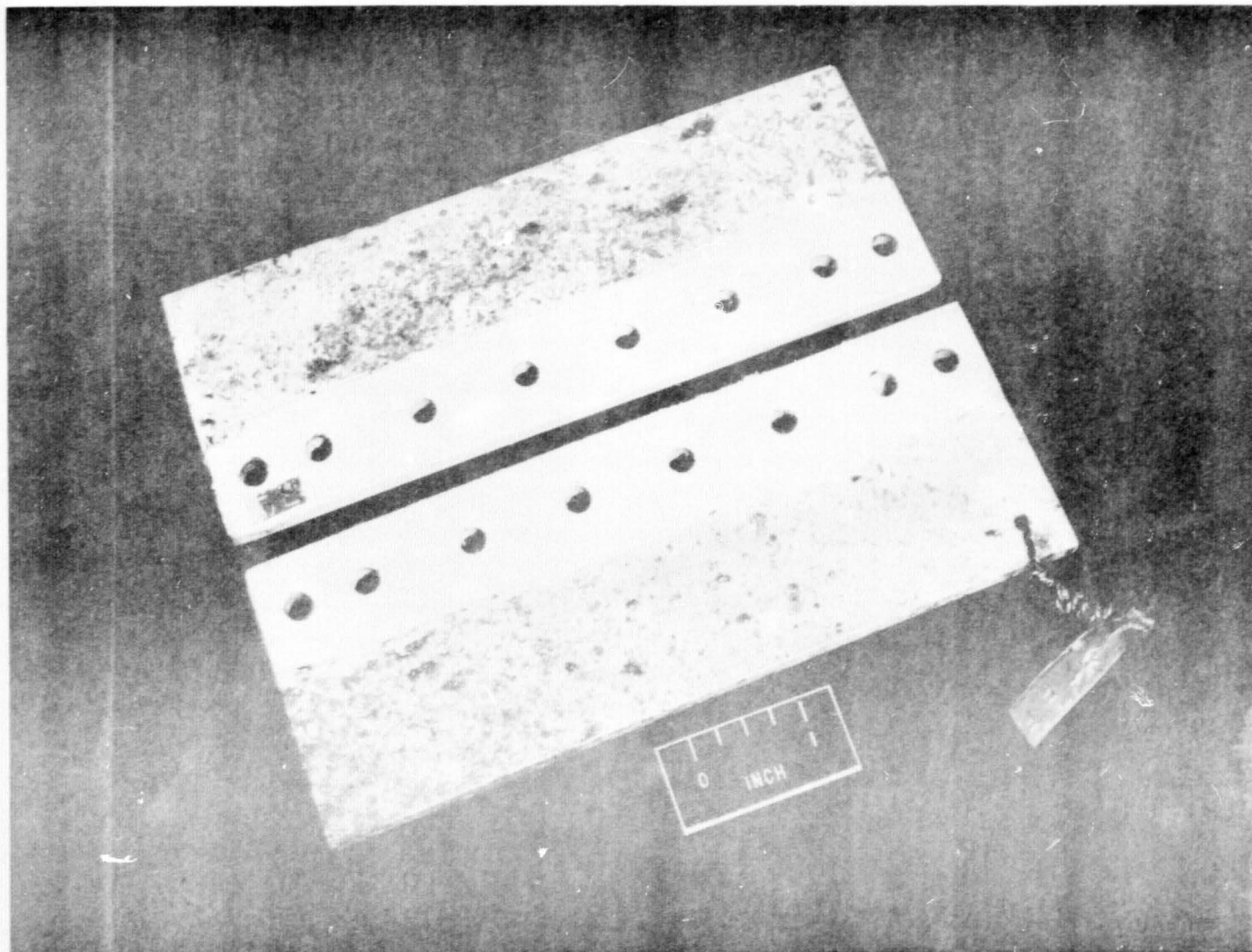


Figure 17. Third Gulf of Mexico test — steel panel showing effectiveness of faying surface sealant — 100 days ocean exposure.

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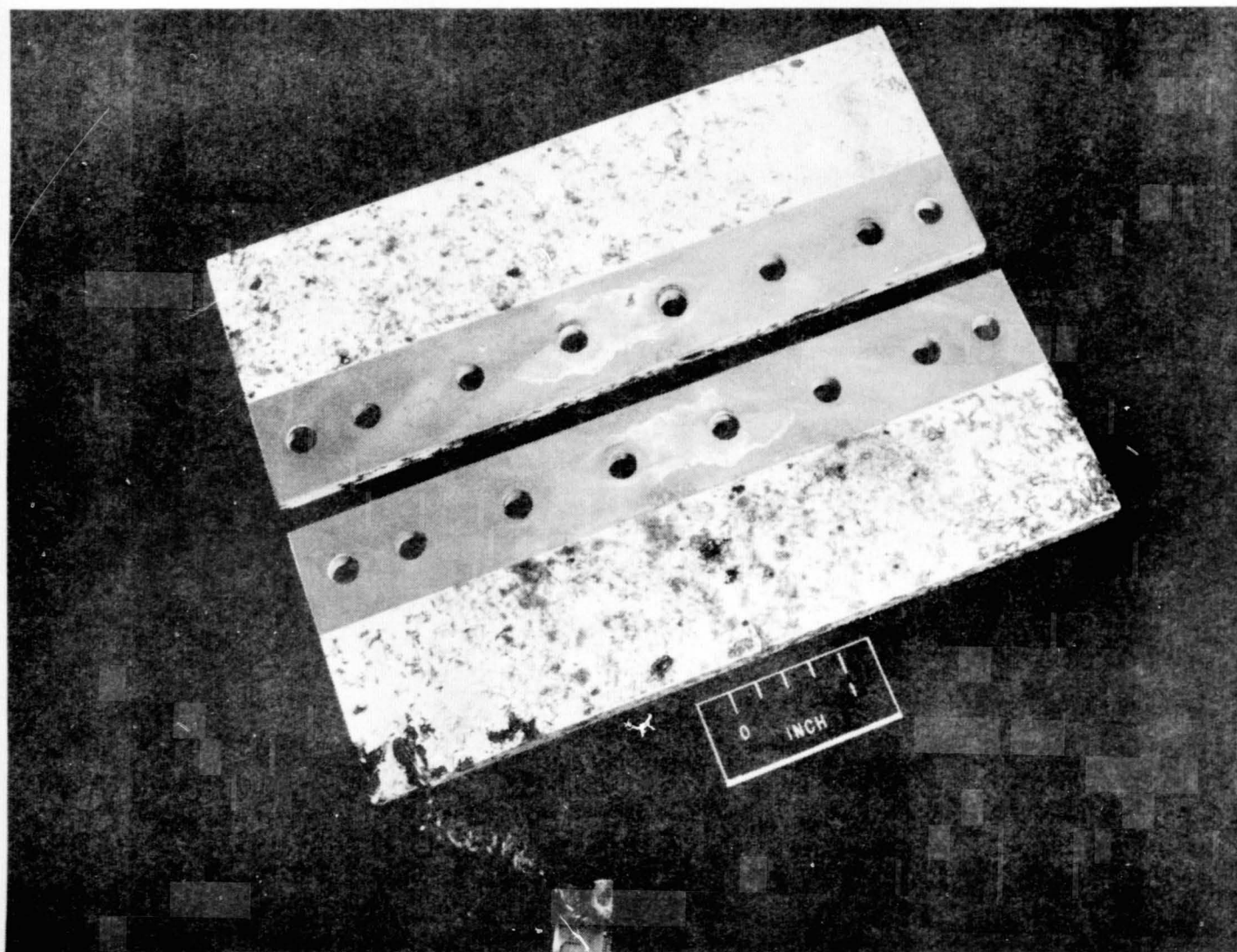


Figure 18. Third of Mexico test — aluminum panel showing corrosion on faying surfaces (no sealant) — 100 days ocean exposure.

c. Conclusions. These tests indicated that galvanize would not be a suitable coating unless a paint coating was applied. The zinc-rich paint system provides excellent protection, is applied by conventional methods, and can be easily repaired. The epoxy chromate paint system offered good protection to the 2219-T87 aluminum alloy. These tests also indicated that fasteners could be used for structural assembly of the skirts, provided excessive temperatures are not reached, the structure is not flexed excessively, and a proper sealant and design are used. For general corrosion protection, the Rust-Oleum zinc-rich epoxy system for steel and the epoxy chromate system for aluminum should provide satisfactory protection for multiflight use involving seawater recovery.

4. Summary of Gulf Tests with Small Scale Samples. To summarize the results of the first three exposure tests in the Gulf, it is readily seen that corrosion presents a problem when steel (such as D6AC, HY-140, and 4130) and aluminum (such as 2219-T87 alloy) are exposed to seawater, unless these materials are protected by very durable coating systems. Other materials such as titanium, Inconel 718, and A286 stainless steel were found to be quite resistant to the seawater and could be satisfactorily used, especially for short exposures, without additional protective coatings. Although durable coating systems were found that would protect the susceptible alloys from general surface corrosion, other areas such as at faying surfaces and around fasteners could present additional problems unless adequately sealed. The coating found to provide excellent corrosion protection on the steel alloys was a Rust-Oleum zinc-rich epoxy primer (No. 9334) with an epoxy topcoat (No. 9392). For aluminum, a Cat-A-Lac epoxy system consisting of a chromate type primer (No. 463-6-3) and topcoat (No. 463-3-100) was found to provide very good corrosion protection. (Note: This coating system is currently known as Bostik with the same number designation.) The silicone sealant (DC 731) used for these tests was found to provide adequate protection to the holes and faying surfaces of panels joined by fasteners. Silicones, although useful at service temperatures up to 500°F, do have several disadvantages. Among these are low adhesion and strength, poor flow characteristics, and nonadherence of paint coatings to the silicones. Provided service temperatures do not exceed 275°F, other sealants are available that do not have the disadvantages of the silicones and should be used.

C. Long Term Material Testing, Protective Coatings, and Sealants

1. Introduction. As the design of the SRE became more complete, it was recommended that additional tests be conducted utilizing typical materials,

configurations, and assemblies. It was also recommended that various sealing materials be tested to evaluate their performance in seawater. Consequently, a test program was initiated to determine the long term effectiveness of recommended coatings and sealants in controlling corrosion of the SRB structural materials. This program was conducted in two phases. The first phase of the program consisted of using small scale samples for screening studies of various sealants. These samples were tested in simulated seawater in the laboratory and at a selected ocean site located at KSC, Florida. Repeated exposures to heat and corrosive environments were made to simulate multiflight conditions. The second phase of this program was the evaluation of an ITB and incorporates various combinations of SRB materials, coatings, and sealants. This structure was used in life cycle exposure, tow back, and refurbishment studies.

2. Phase I — Small Scale Samples (Fig. 1).

a. Discussion. As a result of the earlier test programs, recommendations were made for the optimum protective coatings for aluminum (Cat-A-Lac No. 463-6-3 primer/No. 463-3-100) and steel (Rust-Oleum No. 9334 primer/No. 9392 topcoat) alloys for the SRB. Since the Cat-A-Lac No. 463-3-100 is a flat white coating, the company recommended a No. 443-3-1 gloss white for optimum seawater service. Test specimens were prepared from 2219-T87, Alclad 7075-T7651, and D6AC materials using the recommended paint coatings and eight potential sealant materials. Published data on properties and performance indicated that a polysulfide sealant should be an excellent material for sealing of faying surfaces and fasteners for all the mechanically assembled joints. Some of the characteristics for the polysulfide sealants include: (1) proven service in commercial and military aircraft, (2) pot life from minutes to days, (3) good adhesion to a variety of surfaces, (4) variable viscosities for any type application, (5) no primers required, (6) good storage properties, and (7) low cost. One of the main disadvantages of this sealant is an upper temperature limitation of 135°C (275°F). Seven polysulfide type materials were chosen for evaluation. Variables of the above characteristics were considered in selecting the materials to be evaluated. In addition, one silicone type sealant was evaluated. This material has a favorable performance history, especially for temperatures up to 260°C (500°F) and does not depend on an acidic curing agent.

The test specimens were assembled using Huckbolt type fasteners fabricated from A286 and 7075-T73 materials. Each assembly contained a row of six of each of the two types of metal fasteners. All fasteners were installed using

a wet sealant; however, only one-half of each row of fasteners had a sealant overcoating to completely encapsulate both the fastener head and collar. Several test specimens for each sealant were fabricated. The in-house corrosion test procedure selected was to simulate the environmental cycle projected for the SRB. This test consisted of heating the specimen to 300°F within 5 min (boost phase), quenching in 3.5 percent salt solution after air cooling to 200°F (splashdown), and exposing the specimen to a 7 day duration alternate immersion test in 3.5 percent saltwater solution (recovery). This test cycle was to be repeated for up to 20 cycles with specimens being removed periodically for tear-down evaluation. Four samples of each sealant selected were exposed to seawater (splash zone for 6 days and 1 day in the harbor) at KSC, Florida. After the seawater exposure, one sample was relocated to a beach site for additional exposure simulating launch pad time, and the other three specimens of each sealant were returned to MSFC for evaluation. Subsequent to this evaluation, the specimens were subjected to a cleaning process and returned to KSC for additional beach site exposure. One specimen of each sealant group has a $2 \times 3 \times 1/8$ in. D6AC steel tab attached with A286 S.S. fasteners and coated with the Rust-Oleum epoxy zinc system.

b. Results. Two separate groups of specimens were actually exposed to the ocean at KSC. The first group of panels were inadvertently lost and subsequently found on the beach several miles from the exposure site 57 days later. These panels were visually examined and found to be in excellent condition (Fig. 19). Only superficial mechanical damage was noted. Very light corrosion was noted on a few of the aluminum fasteners which purposely did not have the sealant overlay and the paint (topcoat only) had been scraped off. Also, very little marine growth was noted. The panels were not washed but stored in plastic bags and left in the laboratory. Several weeks later, some of the panels were disassembled and very light corrosion was noted just under the edge of the fastener head or collar on the bare material (Fig. 20). This corrosion was found at several fasteners and was not detectable prior to disassembly. There was no corrosion or other evidence of seawater leakage in the holes or on the faying surfaces. Also, there was no corrosion or other evidence of deterioration at the joint of samples having a D6AC steel tab attached. The second group of panels exposed to seawater at KSC was taken from the in-house test after the first group of panels had been lost (but prior to finding the lost panels). These panels had the following total exposure: 3 heat and exposure cycles in-house (heat up to 148.9°C (300°F) in 5 min, 7 days exposure to 3.5 percent salt solution) and exposure to the ocean for 11 days, detergent cleaning, and 7 additional days in the ocean. This was a total of 39 days exposure to a salt environment. Following

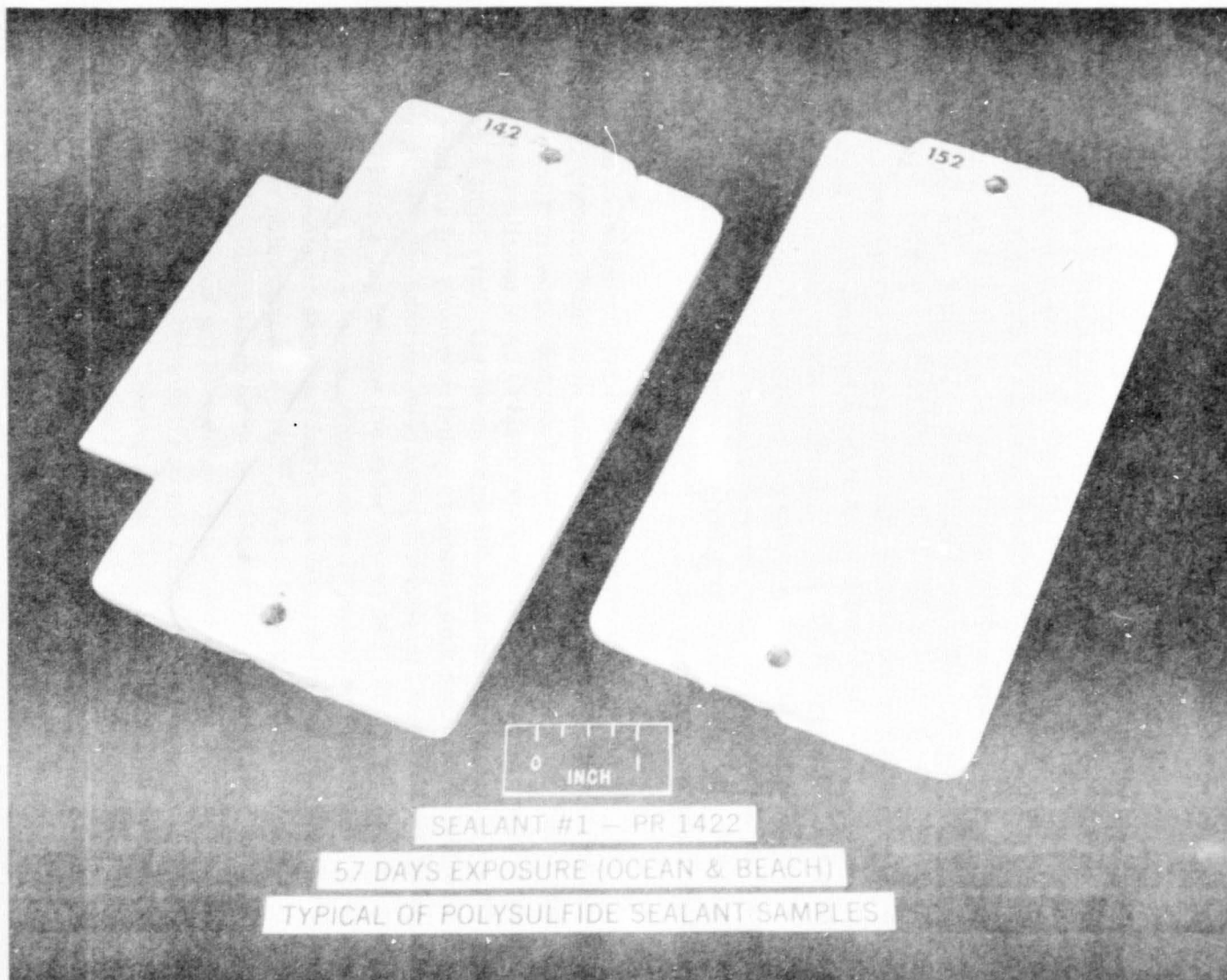


Figure 19. Sealant No. 1 (PR 1422) — 57 days exposure (ocean and beach) — typical of polysulfide sealant samples.

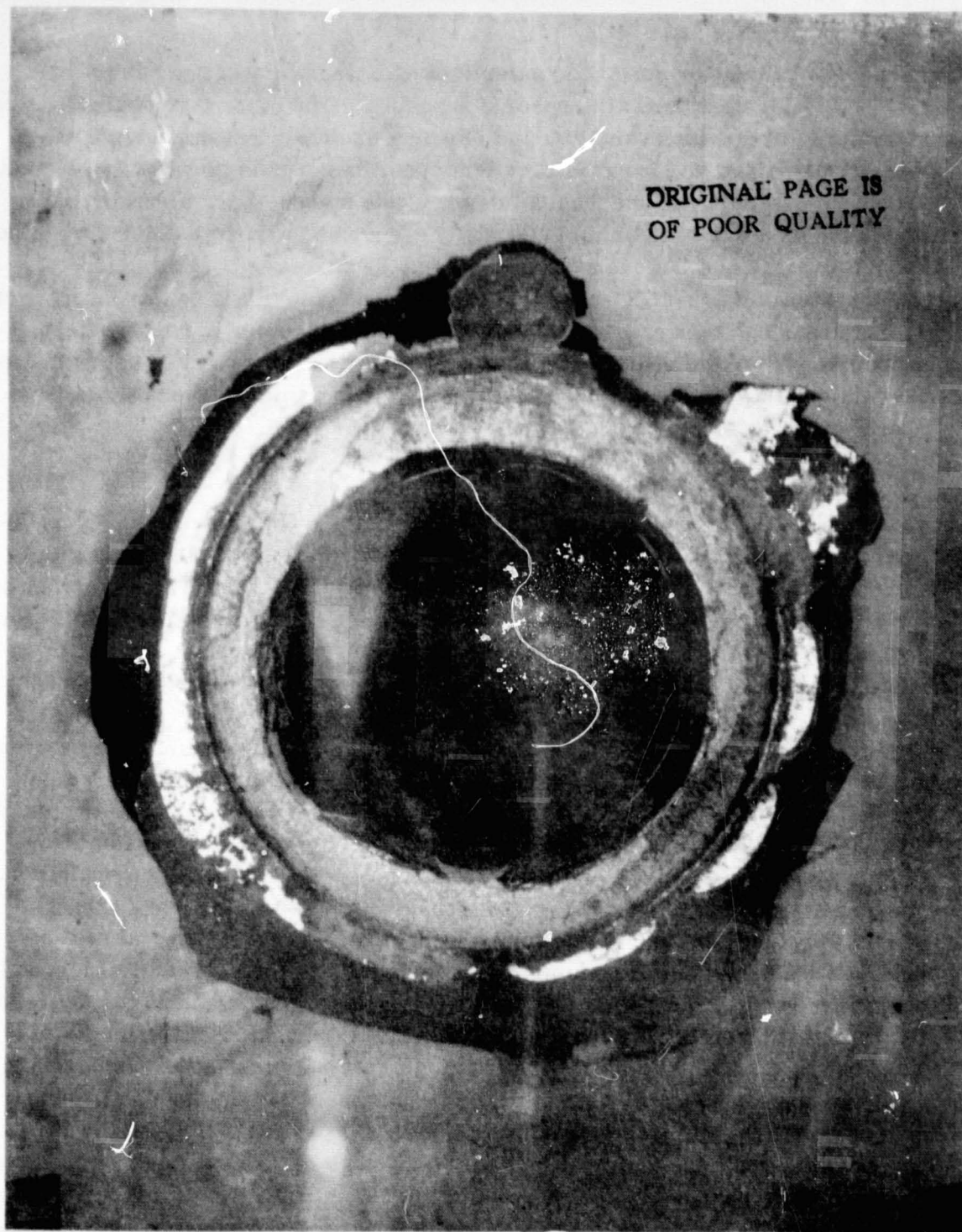
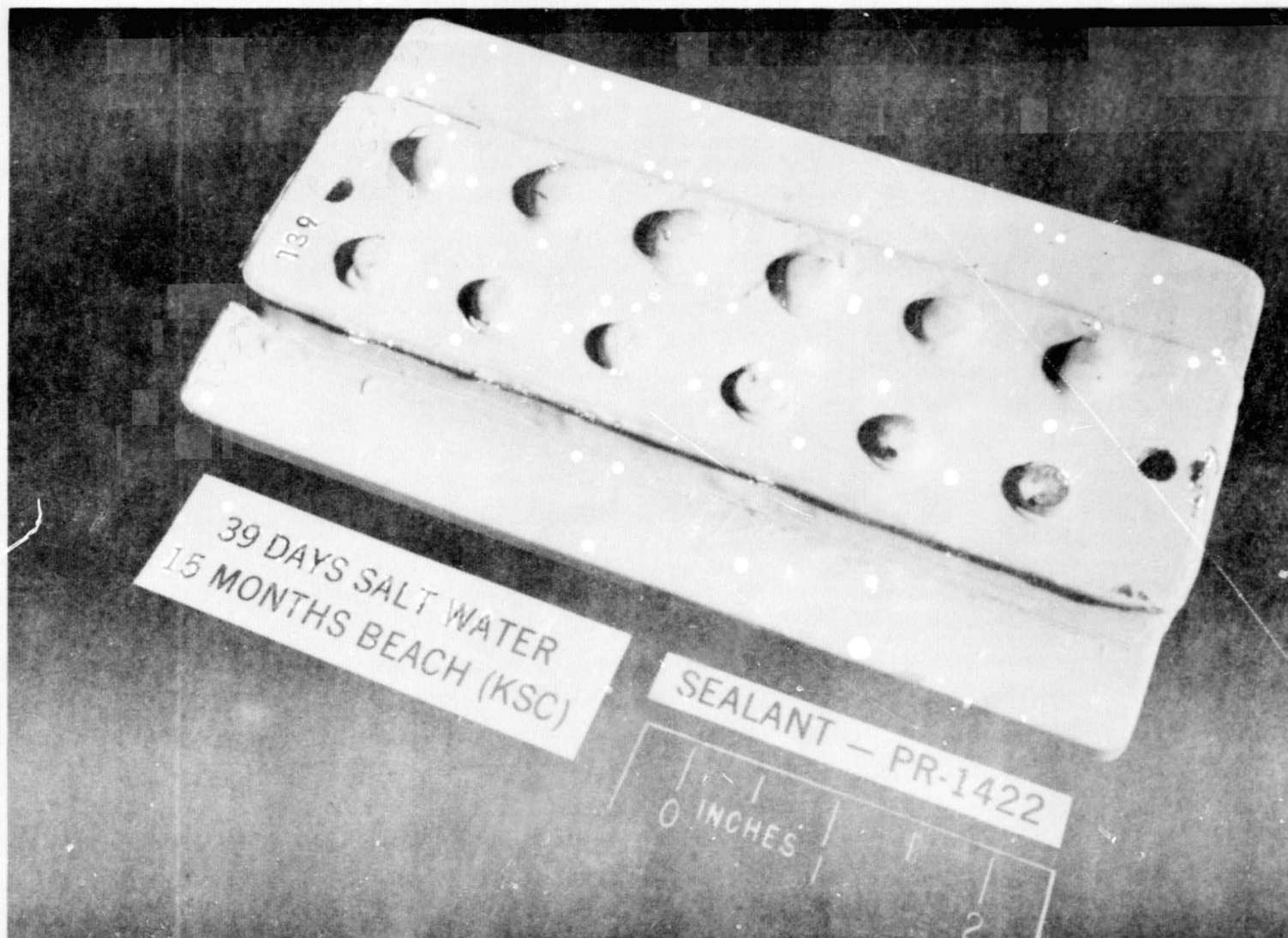


Figure 20. Corrosion under the edge of the fastener head
after 57 days of exposure.

the second ocean exposure, one sample of each sealant was placed at a beach site (KSC) for continued atmospheric exposure. The other three samples were returned to MSFC for evaluation and cleaning studies. These panels were visually examined and found in excellent condition. Again as with the original group, only superficial mechanical damage was noted. Very light corrosion was noted on a few of the aluminum fasteners which purposely did not have the sealant overlay and the overcoat of paint had been scraped. Little, if any, marine growth was noted. Some cracking and peeling of the paint coating over sealed areas had occurred as a result of sealant expansion during the heat exposure. After the visual examination, the panels were cleaned using Turco 5948 detergent solution and returned to KSC for exposure at the beach atmospheric test site.

The four sets of panels were returned for evaluation after beach exposures of 6, 9, 12, and 15 months. In general, the panels were in good condition; however, the paint on all surfaces exposed to the sun had lost its glossy appearance and some light chalking was evident (Fig. 21). The panels exposed for a total of 15 months were slightly more chalked than those with less exposure and appeared to be "washed out;" however, excellent protection was still provided to the aluminum base material. A small amount of chipping of the white topcoat was noted on a few of the edges which apparently occurred during the handling and testing of the panels. Only slight biological effects were noted on a few of the panels (12 and 15 months exposure), and this appeared as small grayish spots similar to mildew stain. On five of the panels, one or two small spots of corrosion were noted adjacent to a fastener prior to disassembly (Fig. 22). Cracking and some flaking of the paint applied over the sealant had occurred. Some of this cracking occurred during the heating cycles that the panels were exposed to. Some flaking of paint was noted on several of the fastener heads and collars which did not have the sealant overcoat. Light white corrosion was noted on the bared aluminum fastener surfaces and the degree of flaking and amount of corrosion was progressively worse with the length of exposure (Fig. 23). There was no rusting of the stainless steel fasteners. Also, no apparent significance could be associated with the cleaning process utilized one time on three sets of the panels. Upon disassembly, light corrosion was noted on the base material just under the edge of several fastener heads and collars. This corrosion did not extend to the hole, but in some cases extended outward ($1/8$ to $1/4$ in.) from the fastener. This was especially noted on samples with the silicone sealant. There was considerably less fastener area corrosion noted on the panels sealed with the PR 1422 polysulfide sealant than with any other sealant evaluated. The most corrosion noted was on panels sealed



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Figure 21. Typical sample appearance (polysulfide sealant) after extended beach exposure.

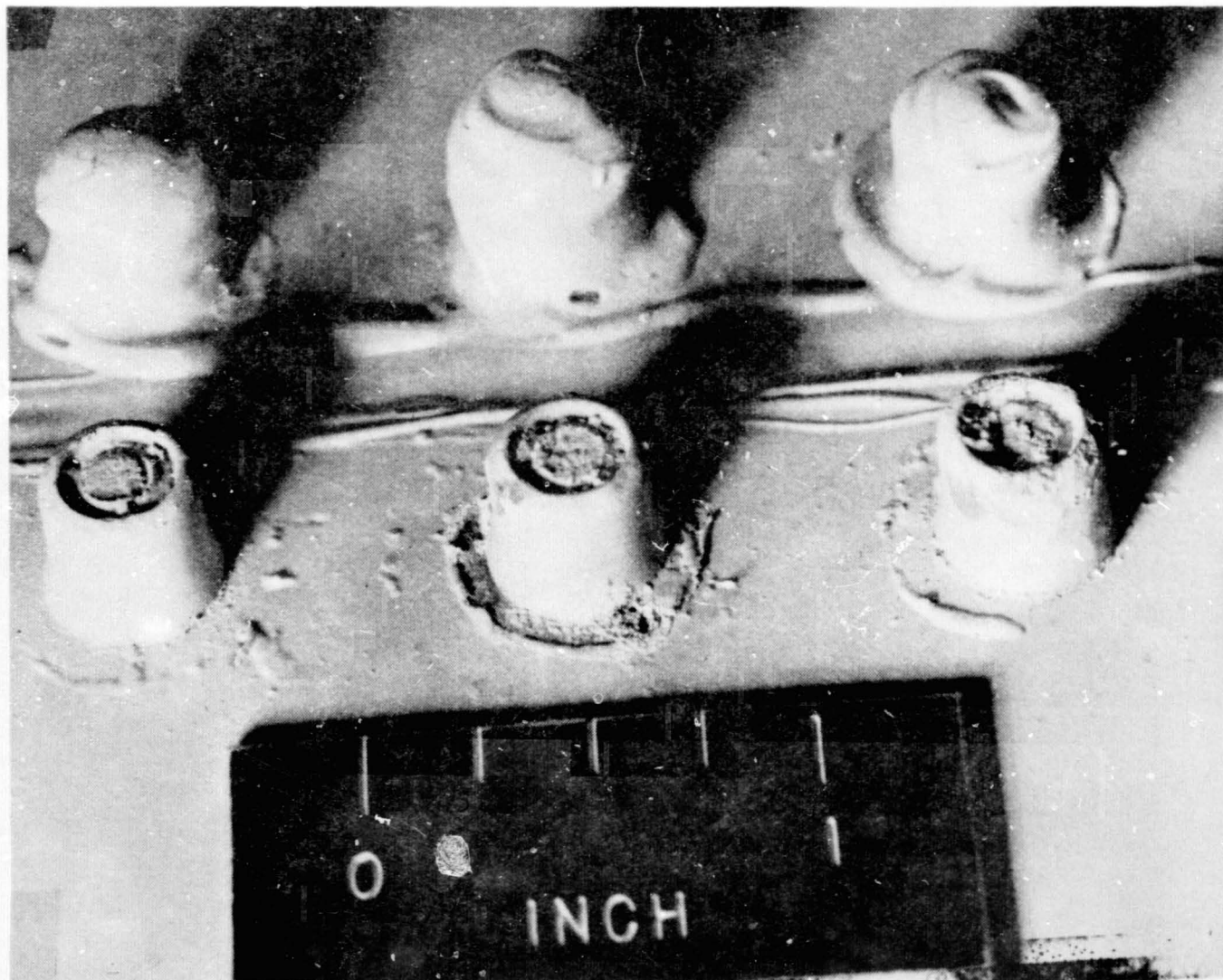
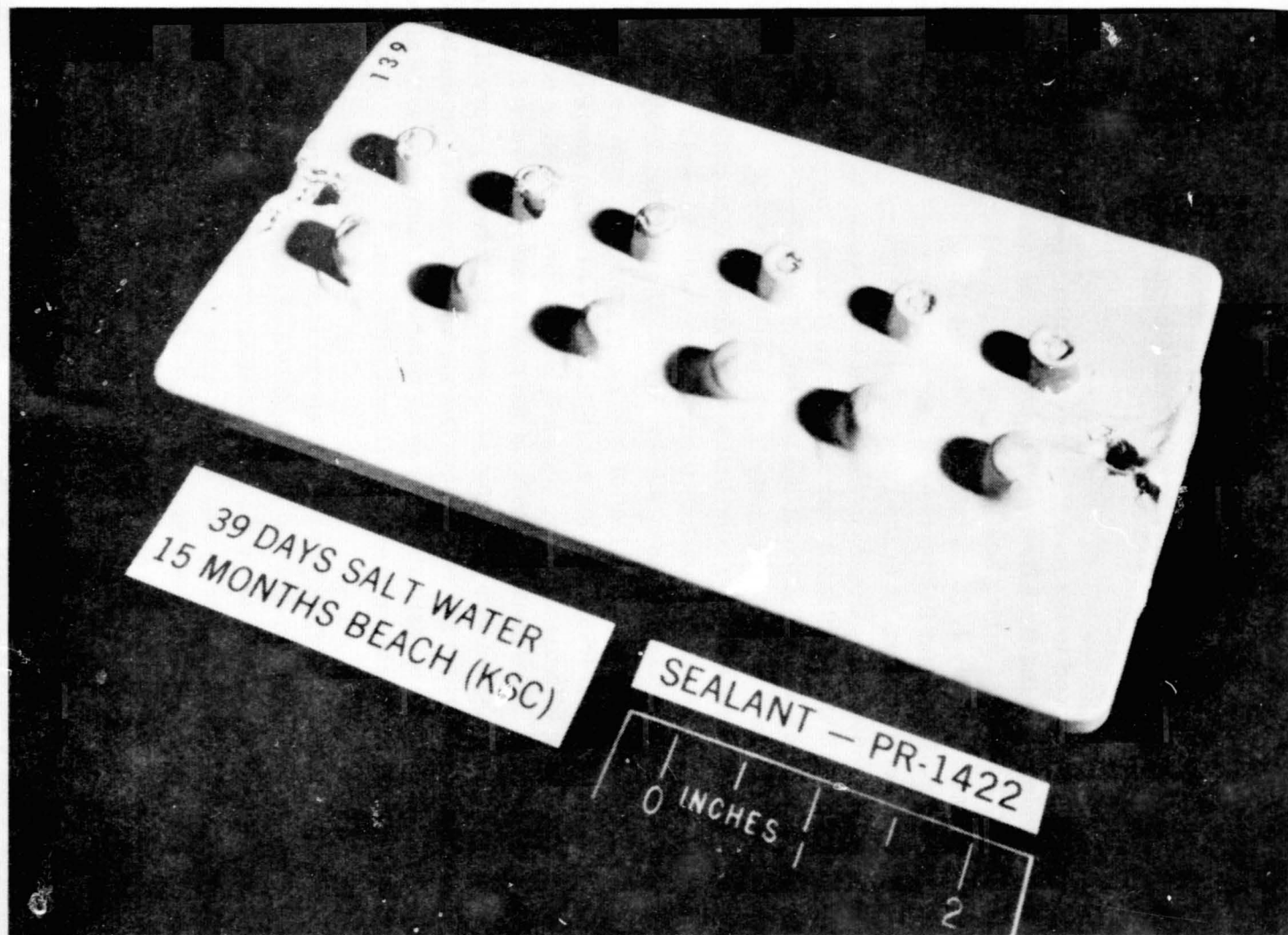


Figure 22. Second ocean exposure — corrosion at edge of fastener — ocean plus 180 days KSC beach exposure.



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Figure 23. Paint flaking and light corrosion on fastener collars without sealant overseal.

with the silicone material (DC 93-076) (Fig. 24). The adhesion of the silicone material was also less than that of the polysulfide material. Some loss in adhesion was noted in the center seam and along the fillets as well as the over-sealing of the fasteners. There was no corrosion noted, however, along the fillets or on the faying surfaces of any of the panels exposed to the seawater and seacoast environments.

Samples exposed to the in-house test were visually examined after each exposure cycle. For the first five cycles, the only degradation noted was expansion of the sealant during heating causing cracks in the paint ranging from hairline to approximately 1/16 in. wide, some heat discoloration (yellowing), and some very minor paint flaking from unsealed fasteners. The silicone sealant had lost considerable adhesion at the fillet between the faying surfaces and on the overseal of fasteners. Minor corrosion had occurred on the bare aluminum fasteners. Examination indicated that the silicone primer had not been applied to these areas prior to application of the sealant. The degree of degradation did not appear to warrant a disassembly inspection at this time. Consequently, the silicone sealant panels were refurbished (externally) with primer and sealant and all samples placed back in test. At the end of 10 cycles, only a small extension of earlier noted degradation had occurred (Fig. 25). In general, the overall appearance was that of heat aging resulting from yellowing of the paint and paint cracks from sealant expansion. Although some loss of adhesion was noted with the silicone, the samples appeared in better condition than after 5 cycles. Two panels of each of the sealant samples were disassembled for inspection. Again, as with the samples exposed in seawater, very light corrosion was noted just under the edge of the fastener head or collar on the base material (Fig. 26). Approximately the same number of fasteners were affected. The holes and faying surfaces were in excellent condition.

At the end of 15 cycles, the overall appearance had changed very little on all samples remaining in test with the exception of panels sealed with sealant No. 7 (a polysulfide). This sealant had swelled excessively out of the center seam as a result of the heating cycle. One sample of each sealant type was removed from test and disassembled. Again, as with the other panels, very light corrosion was noted in the fastener area after disassembly. Approximately the same ratio of fasteners was affected and to approximately the same degree as had been noted earlier. The holes and faying surfaces were not affected. The remaining set of panels was removed from test at the end of 20 cycles. Again, no appreciable change was noted except for a slight increase in the yellowed aged appearance. Hairline cracks were noted in the paint coating

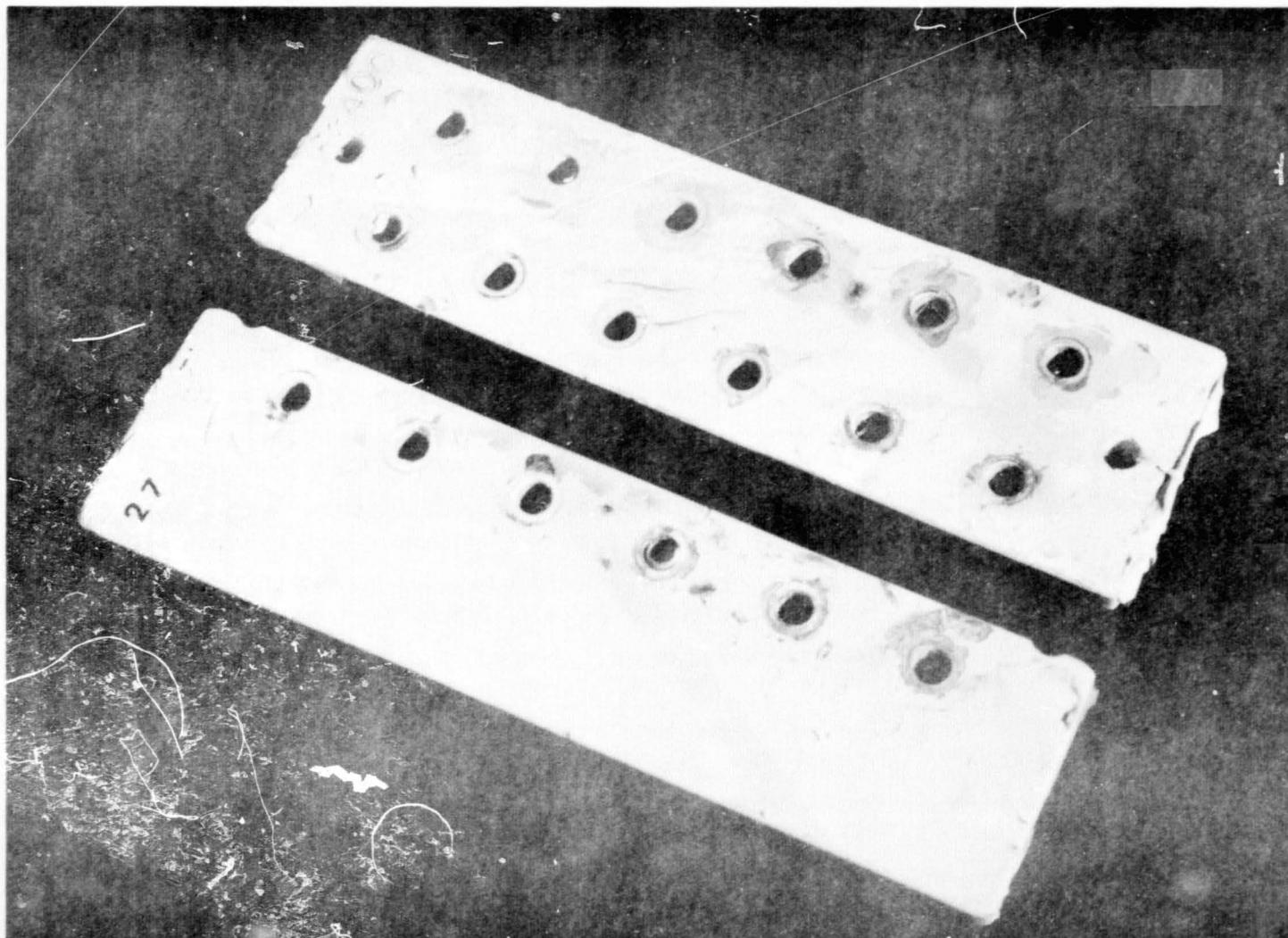


Figure 24. Corrosion around stainless steel fastener areas with silicone sealant (15 and 20 in-house test cycles).

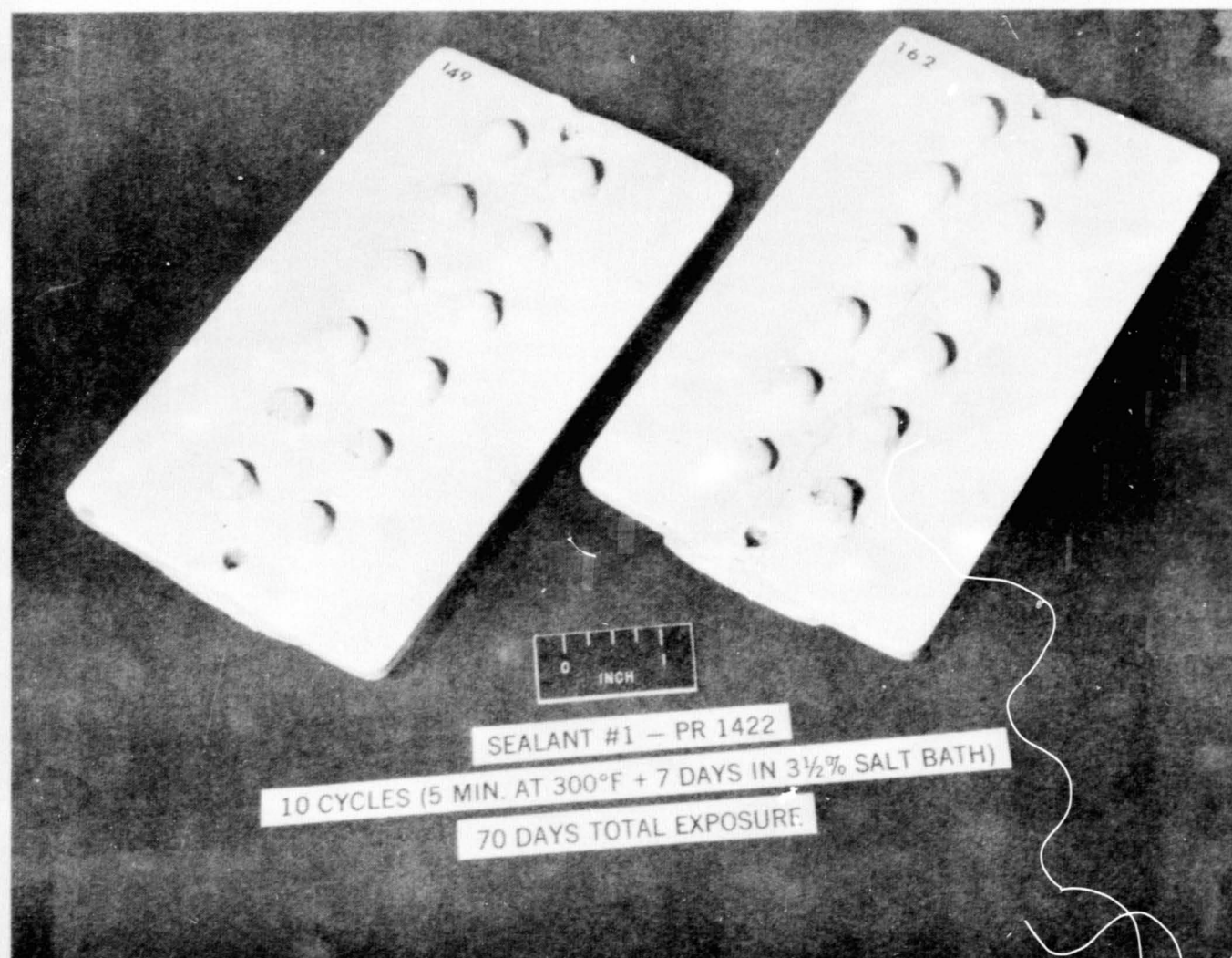


Figure 25. Ten cycles in-house exposure (typical appearance of samples sealed with acceptable polysulfide sealant).

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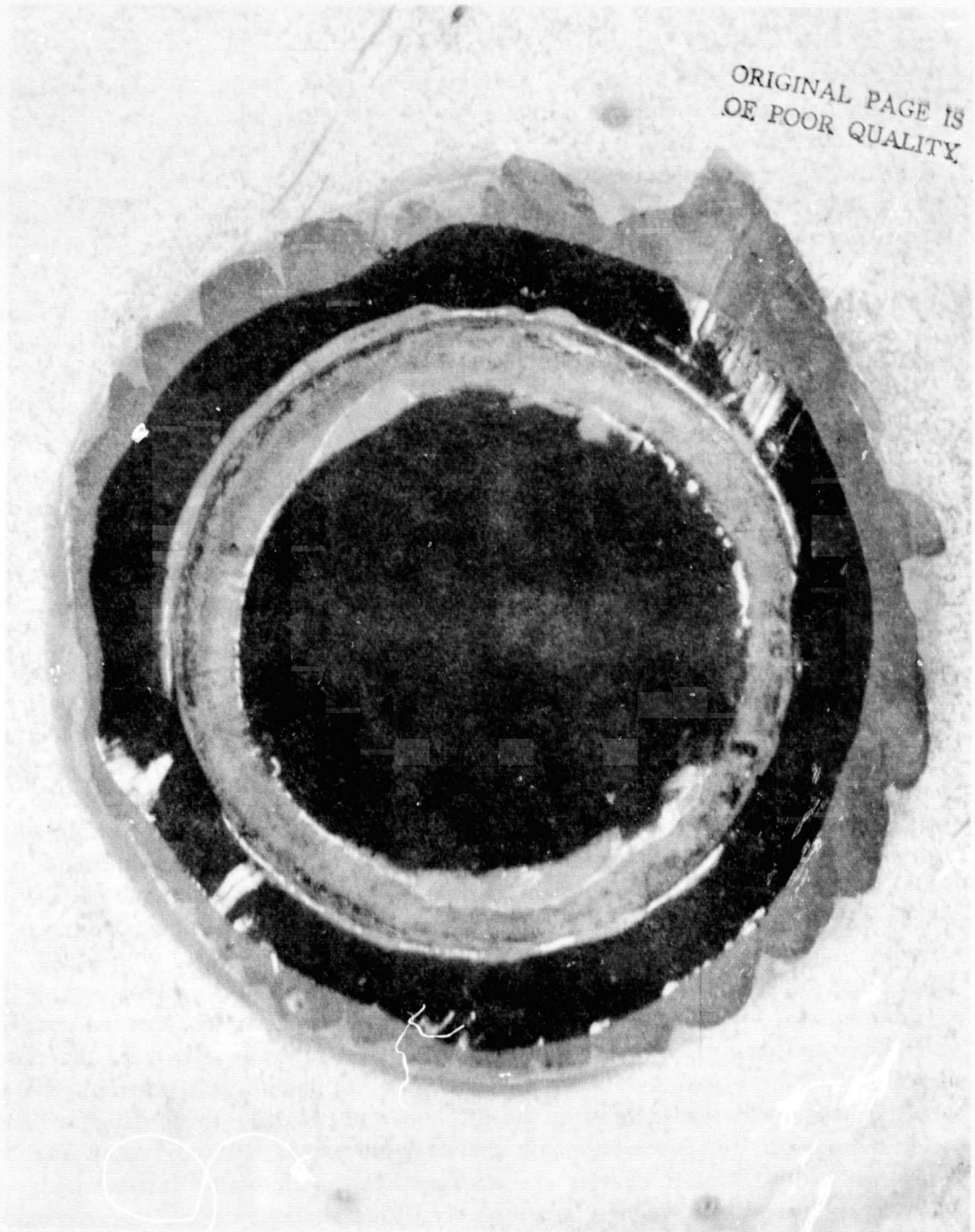
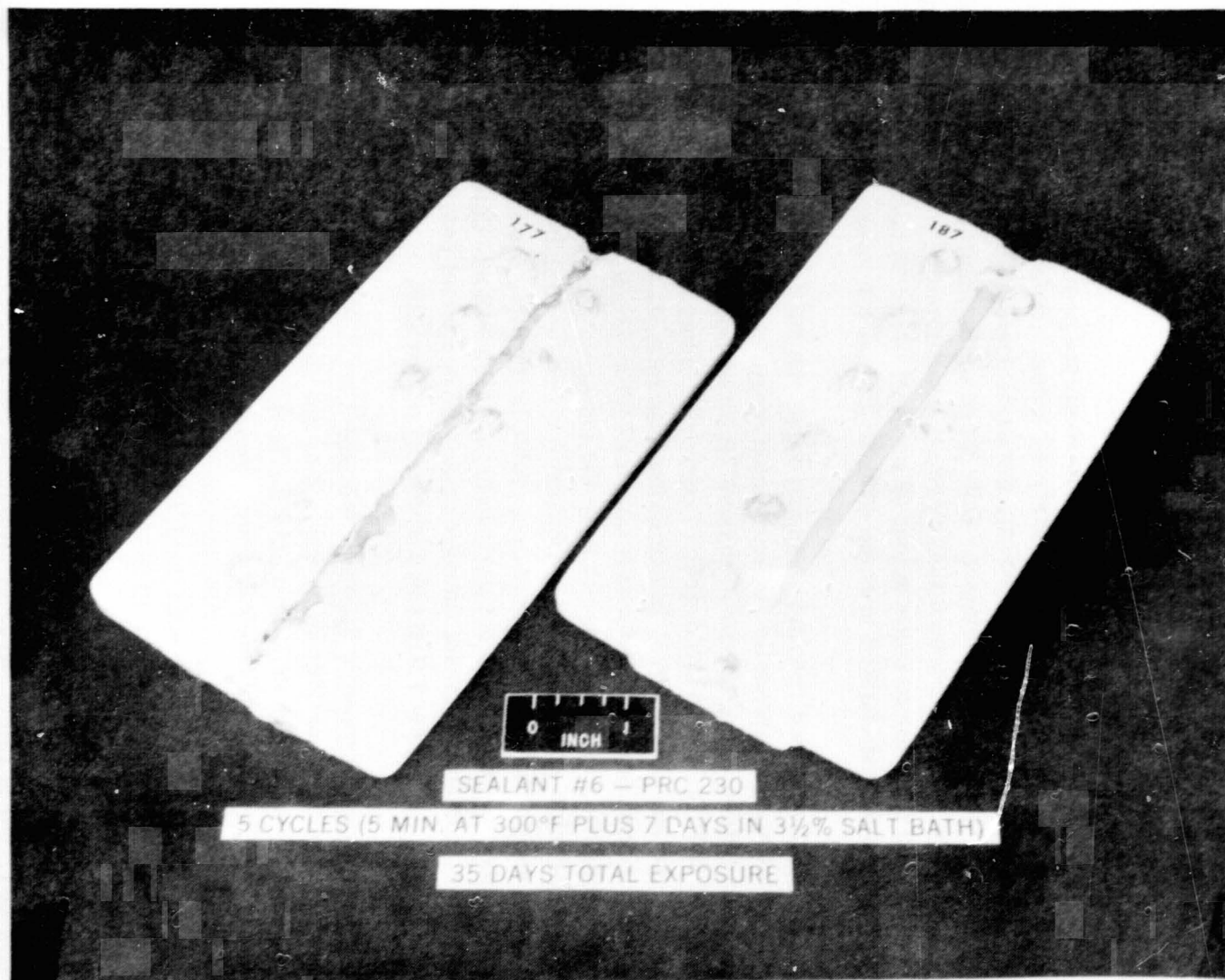


Figure 26. Ten cycles in-house exposure (corrosion under head of aluminum fasteners).

over the sealants with some light flaking. Also some flaking of paint was noted on fasteners coated with paint only and bared aluminum fasteners had light general corrosion. Upon disassembly, similar results were noted as before with light corrosion observed in some fastener areas. Although this corrosion was noted on samples after exposure to only 5 test cycles, the severity did not visually appear to be significantly worse on the panels exposed for 20 cycles.

c. Conclusions. The results of these tests clearly indicate the outstanding performance of the PR 1422 polysulfide sealant. Throughout the entire test series, less sealant degradation and better corrosion protection in the fastener area were provided than with any other sealant evaluated. Two of the polysulfide materials were eliminated early in the test program due to excessive expansion of the sealant upon heating (Fig. 27). Two others were eliminated after the tenth and fifteenth cycles for this reason as well as corrosion found in a large number of fastener areas. Of the three remaining polysulfide materials, there were fewer incidences of corrosion noted in the fastener areas with the PR 1422 sealant than with the other two sealants. This was very apparent in both the sea/seacoast and in-house tests.

The silicone sealant (Dow Corning 93-076) offered somewhat less protection to the fastener area than the polysulfide sealants. Corrosion was noted at 59 out of 240 possible areas of (25 percent) on the silicone sealed samples and at 17 out of 216 possible areas (8 percent) on the PR 1422 sealed samples. The corrosion noted in the fastener area of all panels was considered light and in most instances was not detected until disassembly. Close examination of these areas indicated that during the fastener assembly the heads and collars of the fasteners had deformed the base material, causing the paint coatings to crack and leaving a peaked uneven edge of bare aluminum (Figs. 20 and 26). Apparently, incomplete sealing of these areas permitted saltwater entry and corrosion to occur. In general, the corrosion noted was not considered severe even after the long saltwater exposure of 20 cycles or the lengthy sea/seacoast exposure. Panels sealed with the silicone material had slightly more corrosion than the polysulfide sealants after the fifteenth and twentieth cycle exposure and after the twelfth and fifteenth month seacoast exposure. The corrosion was associated with the stainless fasteners more than the aluminum fasteners and with the silicone sealant more than the polysulfide sealant. Also, the corrosion noted with stainless fasteners was associated more with the collar area than the head area while just the opposite was noted with the aluminum fastener. The additional protection afforded to the fastener area by oversealing was very obvious, especially with the aluminum fasteners. Corrosion was noted at only



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Figure 27. Five cycles in-house exposure — sealant expansion due to heat cycle.

8 out of 258 possible areas (3 percent) with the aluminum fasteners having an overseal while 31 out of 198 possible areas (15.7 percent) without the overseal were affected. With the stainless steel fasteners, 41 of 198 possible areas (20 percent) with the overseal and 40 of 138 possible areas (29 percent) without the overseal were affected.

Another important finding was the complete protection afforded by all sealants to the faying surfaces and fastener holes. No evidence of corrosion was noted in these areas. In general, the paint coatings provided excellent protection to the general surfaces. Only three or four small spots of corrosion were noted on all panels tested that were not associated with the fastener area. The paint did discolor to some extent as a result of the 20 heat cycles on the in-house panels and chalked to some extent with the KSC seacoast exposure.

Based on these results, it appears that the PR 1422 sealant and Bostik epoxy paint system presently recommended by specification offer excellent corrosion protection to aluminum assemblies and would be satisfactory for SRB use up to 300°F. While the degree of corrosion protection afforded by the silicone sealant (DC 93-076) is somewhat less than that of the polysulfide sealant, it does have merit for use where a higher temperature (300 to 500°F) sealant must be used. It does not have the adhesive strength of the polysulfide, but does provide adequate sealing wherever it can be contained, such as faying surfaces and in the holes of fasteners. Adequate protection should be afforded for a number of reuses without serious degradation. Some damage is expected to occur with each use cycle; therefore, some repair and refurbishment will be necessary following each flight and recovery of the SRB.

3. Ocean Exposure Tests — Summer 1977. Several test panels coated with the protective coatings to be applied to the SRB were included in this study to gain additional ocean exposure data for corrosion and biological purposes. Four 7075-T73 and two 2219-T87 aluminum panels (4 by 6 by 1/8 in.) were coated with the Bostik epoxy paint system. Six panels of D6AC steel (12 by 12 by 1/2 in.) were coated with Rust-Oleum epoxy coatings, three each with red-lead primer and zinc rich primer and topcoated with white epoxy. These panels were also exposed to the ocean for 6 days at KSC followed by 1 day in the Banana River.

A visual examination of all panels was made after the ocean exposure and again after the one day exposure in the Banana River. All aluminum panels were found to be in excellent condition and only a very small amount of biological

growth noted in a few areas. About the same amount of biological growth was also noted on the steel panels painted with the Rust-Oleum epoxy coatings. The greater part of the biological growth noted, however, appeared following the 1 day exposure to the river. This observation was even more pronounced on bare unprotected areas of the test rack.

The protective coatings applied to the steel panels provided excellent protection although light blistering was noted on almost all panels. The blisters were larger on the panels painted with the zinc rich primer than on the panels with the red lead primer (Fig. 28). Several factors are well-known that can contribute to the blistering of protective coatings. Among these are poor surface preparation (contamination), poor application techniques resulting in pinholes, moisture entrapment, thin topcoats, and incomplete drying between coats. In many cases, there is not a main contributor, but a combination of several small conditions that add up to result in blister-type failures. Investigations of these blistered areas were conducted in-house and by Rust-Oleum technical service personnel, and it was concluded that the most likely cause of the blistering was inadequate topcoat coverage. Thickness measurements of the topcoat indicated that the blisters occurred in areas where the coating was less than 0.0015 in. thick. The Rust-Oleum representative stressed the importance of adequate topcoat coverage and stated that our requirement of 0.0015 to 0.002 in. of primer and 0.0015 to 0.002 in. of topcoat was satisfactory. It must be emphasized that good painting practices, coating thickness requirements, and strict adherence to the paint manufacturer's guidelines must be followed so that maximum performance can be attained when these coatings are to be utilized for corrosion protection during immersion service.

During the long term test program to evaluate various sealants for the SRB, information was obtained relative to polysulfide sealants formulated to include a soluble chromate corrosion inhibitor. The soluble chromates were included to provide a measure of additional corrosion protection to mechanical assemblies, especially where incomplete sealing had occurred or seal integrity had been damaged. In a continuing effort to provide the best possible protection to mechanical assemblies which will be exposed to seawater, an initial comparison of this type of sealant with the presently recommended PR 1422 polysulfide sealant was made. Since these sealants will be required to seal a variety of fastener types, several variations of fasteners were included to study the sealing characteristics with various surfaces.

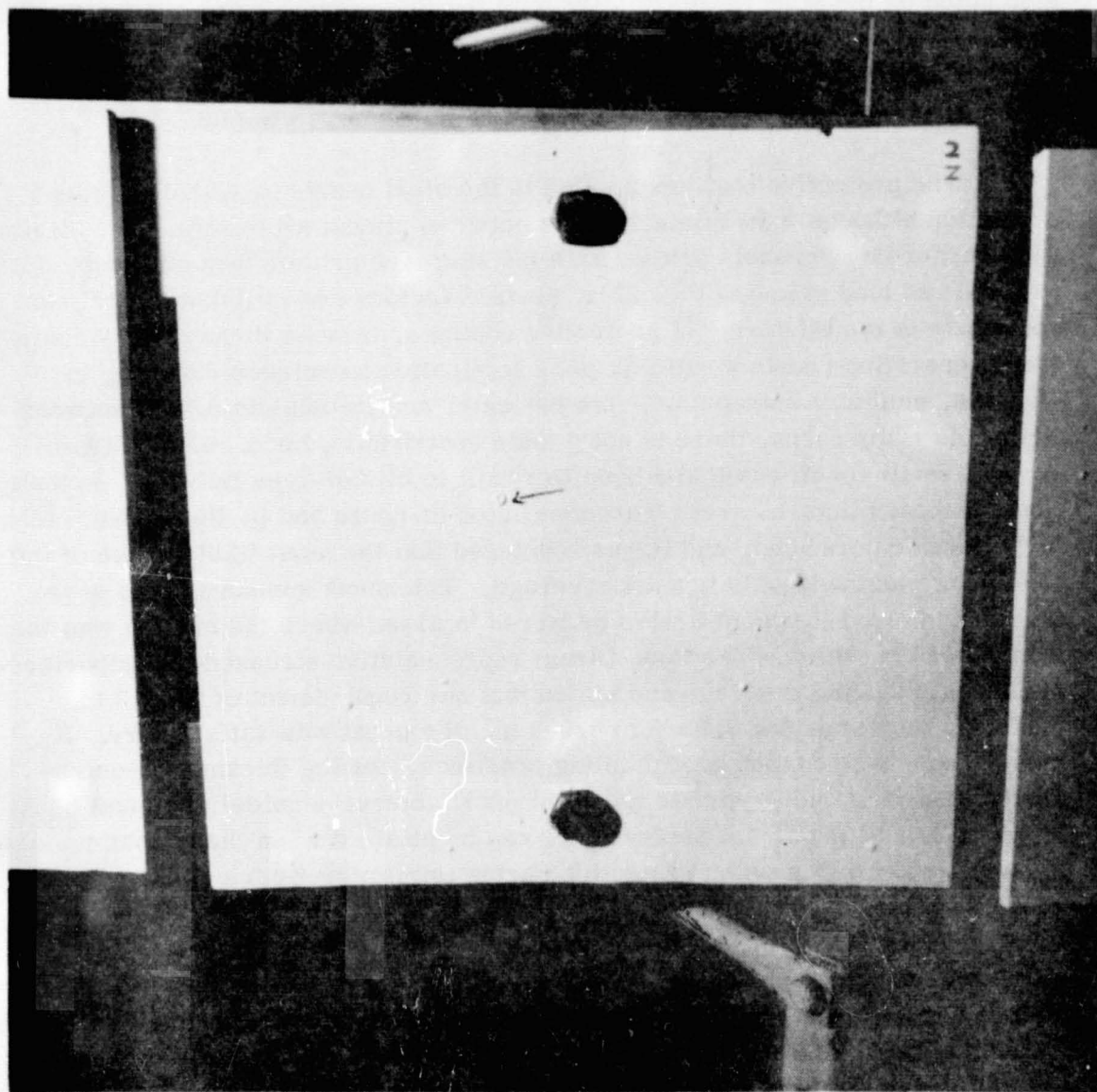


Figure 28. Blisters on D6AC steel panel after ocean testing —
Rust-Oleum zinc-rich epoxy system.

Panels of 2219-T87 aluminum alloy 4 by 10 in. were prepared by drilling four rows of holes and painting with the Bostik epoxy system in accordance with Drawing No. 10A00528. Fasteners were then assembled into the panels in accordance with Drawing No. 10A00527 using one sealant for each panel with all fasteners oversealed (Fig. 29). The sealants utilized in this study included PR 1422, PR 1436G (with soluble chromates), and DC 93-076 silicone. Fasteners used included bare A286 stainless steel bolts and bare, cadmium plated, and dry film lubricated nuts; A286 Huckbolts with cetyl alcohol lubricant; A286 Hi-Loks with cadmium plate; and aluminum Huckbolts.

After exposure to the ocean for 6 days and the Banana River for 1 day, a visual examination of the panels did not reveal any changes except a slight biological growth in a few areas. After returning to MSFC, the panels were cut to show a cross section of several fasteners and some fasteners were disassembled without cutting. In all cases, the two polysulfide sealants appeared to provide excellent sealing with very good adhesion of the sealant overseal. Excellent sealing was also noted with the silicone sealant. Although the adhesion of the silicone overseal was less than that of the polysulfide sealant, the adhesion was satisfactory in most cases.

It is recommended that additional studies be conducted with the PR 1436G sealant to determine its heat resistance and long term protective qualities for SRB use.

4. Phase II — ITB.

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a. Results of Inspections. The ITB was fabricated to represent several SRB assemblies and incorporated most combinations of SRB materials, coatings, and sealants. Several inspections of the ITB were made after exposure to the seawater and harbor areas at KSC (7 days in the ocean and 3.5 days in the Banana River). Painted surfaces were in excellent condition with the exception of scarred and damaged areas (from handling and excessive flotation removal). These areas were covered with heavy marine growth and some corrosion products where the damage extended down to bare metal (Fig. 30). One of these areas was closely examined and corrosion on the aluminum was minimal. Light rust was noted on bare stainless steel fittings and flex hoses mounted inside the ITB. Heavy marine growth was also noted on scarred areas of an electronic component mounted to the inside wall. All fastener areas appeared to be in very good condition with the exception of nonadhesion of the silicone sealant on a very few of the fasteners and the flaking of the epoxy paint

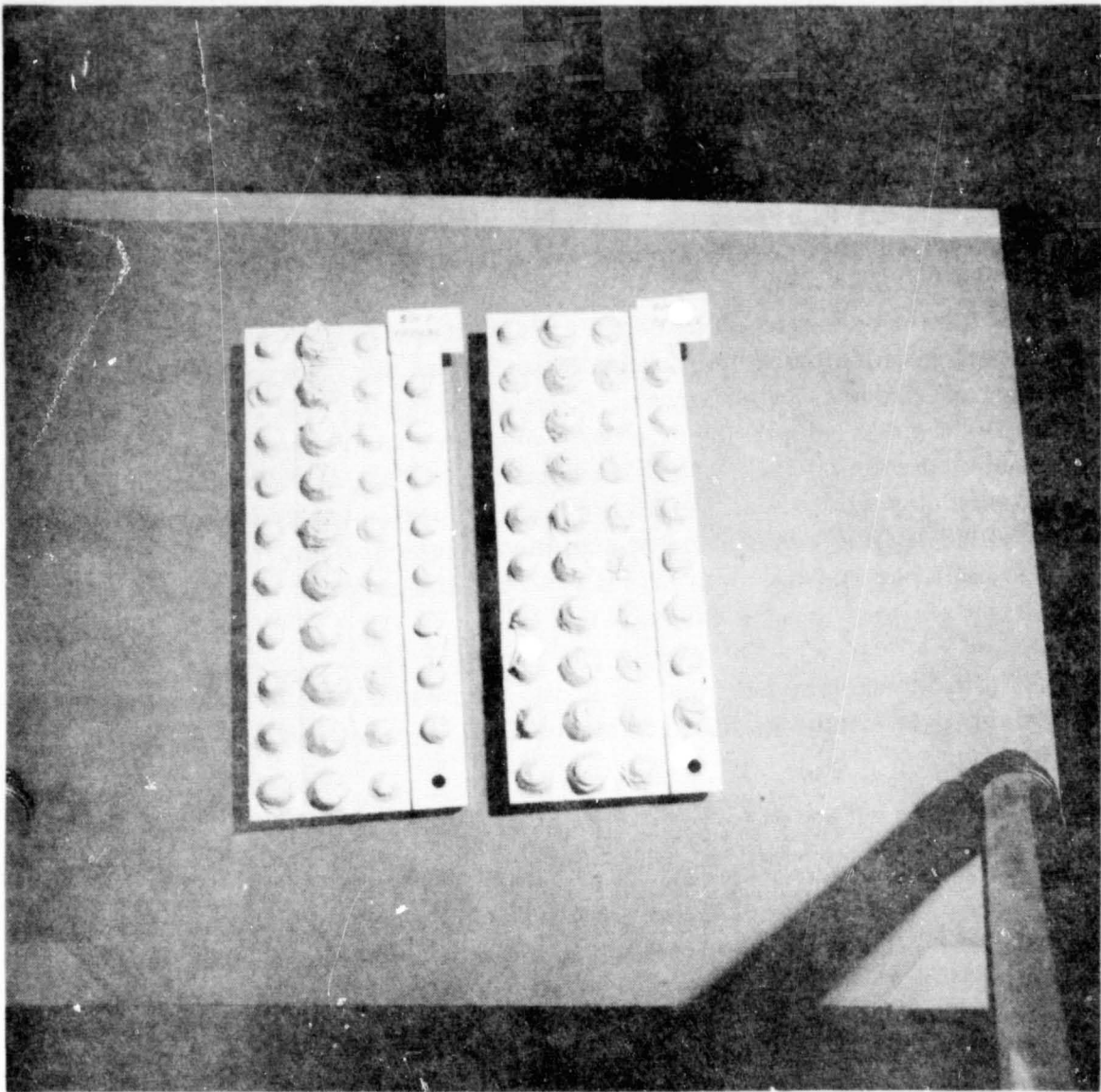
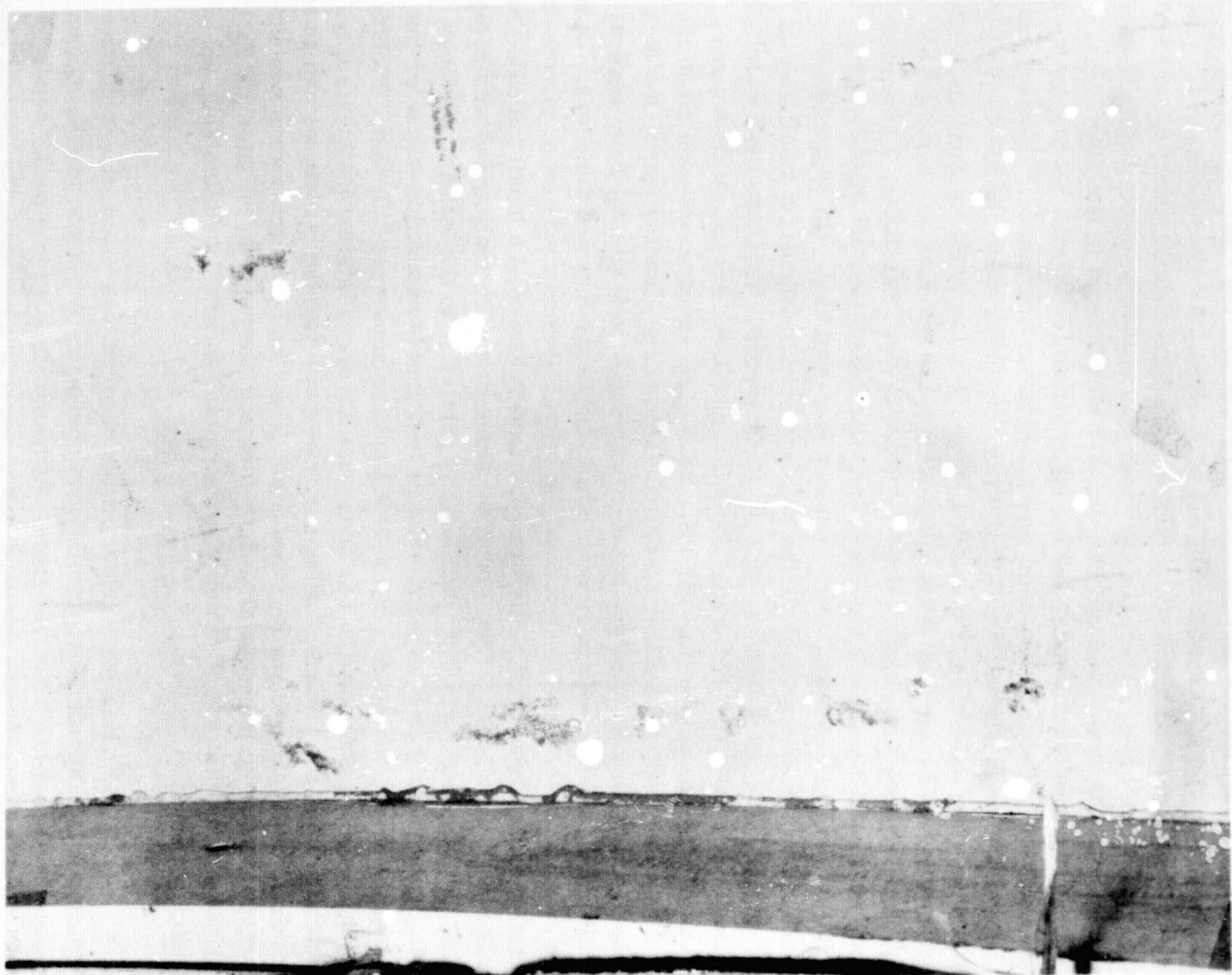


Figure 29. 2219-T87 aluminum panels with fasteners sealed with two polysulfide sealants after ocean exposure.

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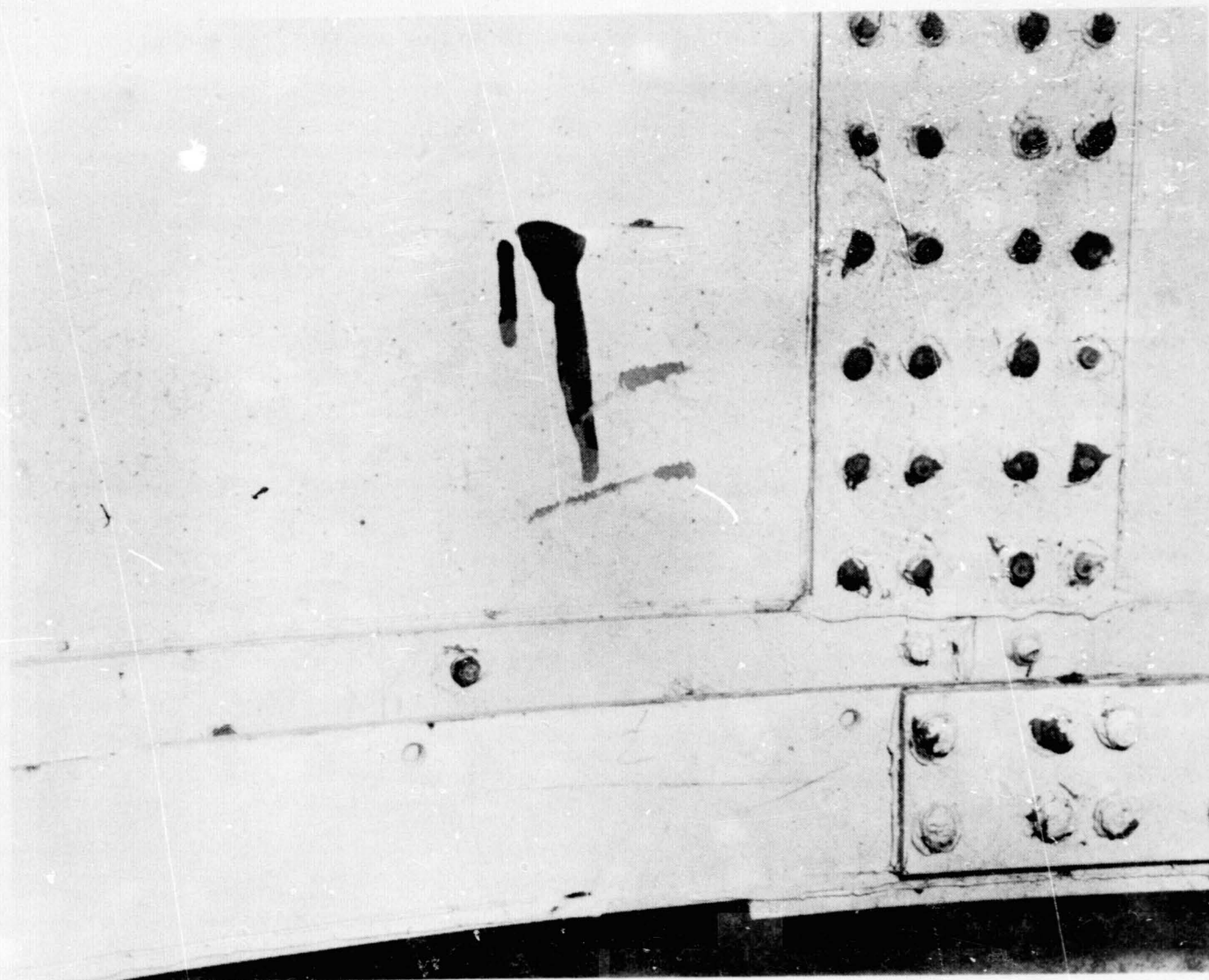


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Figure 30. Corrosion and marine growth at damaged areas on ITB.

overcoat on the silicone (Fig. 31). (Note: Large dark area is adhesive residue.) Considerable dirt and soil were found on the interior of the ITB which resulted from the final exposure at the dock site in the river (Fig. 32). After the ITB was returned to MSFC, a closer inspection did not reveal any additional significant findings. The clevis joint seal appeared to be intact, both inside and out. During the next 4 to 5 months, the ITB was located in Building 4707, except for one outdoor display lasting approximately 1 week. During the cleaning and disassembly of the ITB, additional inspections were made. Upon separation of the two halves, a small amount of water was observed in the clevis joint which gave a positive indication of chlorides (more than tap water). Rust discolorations were noted in several areas; however, when the rust was removed no significant attack was noted. Also, 3 stainless steel Huckbolts, 3 aluminum Huckbolts, and 2 stainless steel bolt and nut assemblies, all installed with DC93-076 silicone sealant, were removed and examined. No corrosion was observed on the fasteners or on the base material; however, a small ring of flaked paint was noted around some of the fasteners. This may have resulted from poor installation technique. Only large bolt and nut assemblies were installed with the polysulfide sealant. None of these were removed since the sealant was found in excellent condition. During the cleaning cycle, the high pressure washing removed the overseal cap of silicone sealant from several additional fasteners. No corrosion was noted on the exposed fasteners. During the rework phase of the first section, several tiny imperfections or pimple-like blisters were discovered. Further examination revealed a small corroded area underneath the blister. The corrosion attack was very shallow and was removed with light sanding. Also, it was confined primarily to the interior surfaces. This type of attack had not been noted on test panels exposed in-house or the ocean; however, the history of the ITB has been somewhat different. Flotation tests were first conducted in the Tennessee River. Flotation materials were attached inside the ITB and mating surfaces (with painted structure) and were not dried or cleaned following exposures. Then the ocean tests were conducted and approximately 5 months elapsed before any cleanup was initiated. Considering the overall history, it is not surprising that some minor blistering and corrosion occurred.

b. Conclusions. Based on the observations noted, the protective system utilized appeared to provide good corrosion protection for the exposures encountered thus far in the program. Although some corrosion did occur in areas where the paint was damaged and under small blisters, the overall amount was not significant and was easily removed. The nonadhesion of the silicone sealant overcoat on fasteners does present some concern. This poor adhesion had been noted earlier on the small test samples; however, when used between faying surfaces in bolt holes or other areas where it can be contained, it does provide satisfactory sealing.



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Figure 31. Nonadhesion of silicone sealant to fastener head and flaking of paint from silicone sealant on ITB.



Figure 32. Dirt and soil on surfaces of ITB after exposure to ocean and river.

IV. TEMPORARY SOFT-FILM PRESERVATIVES

Several areas of the SRB will require some type of temporary protective coating, especially the clevis joint area. Because of the close tolerance and sealing of the clevis joint, no paint or other hard film coating can be used. This means that bare D6AC steel will be exposed to the environment. Due to the susceptibility of the steel to general corrosion, some type of protection is mandatory for reuse of the SRM. The Thiokol Corporation recommended a Braycote material (No. 137) (which meets Military Specification MIL-C-16173, Type 2) for application to the bare D6AC steel clevis joint area and other areas of the SRM requiring temporary protection (such as during shipping, fabrication, or storage). Although materials meeting this specification are well known for their preservation qualities, an evaluation of Braycote No. 137 was desirable. The Braycote material was applied to several samples of mild steel (4130 steel and D6AC steel) and subjected to various corrosion tests. The Braycote material was found to provide very good temporary protection to these steel surfaces. Tests included 18 months laboratory, high humidity, and sheltered outdoor exposures; 7 days to a swirling 3.5 percent salt solution; and 1 week in a 5 percent salt spray. Several other materials have been evaluated but do not offer the degree of corrosion protection that the Braycote material does. Braycote No. 137 was applied to the ITB clevis joint area prior to sealing. As previously reported, subsequent to testing in the ocean, the clevis joint area was found to have small amounts of water upon separation. Rust discolorations were noted on the coated steel surfaces, but when the preservative and rust were removed, no appreciable changes to the steel surfaces were noted.

One other use for a temporary coating has been identified. Upon removal from the water after recovery, damaged, abraded, and bare surfaces of the SRB will require protection to inhibit any corrosion until refurbishment. For this use, a MIL-C-16173 Type 3 water displacing thin film preservative is recommended. A Braycote material (No. 157) has been evaluated and found acceptable for this use; however, any product meeting the QPL of this specification should perform satisfactorily.

V. MARSHALL SPRAYABLE ABLATOR

A. Discussion

The leading candidate material for large-area coverage of the SRB TPS is a low cost, low density sprayable ablator identified as Marshall Sprayable Ablator (MSA-1). This material had previously been evaluated in thermal tests, aerodynamic heating tests [in the Arnold Engineering Development Center (AEDC) Tunnel C facility], and in thermal/acoustic environment tests, all with acceptable thermal performance. It was considered essential to demonstrate the processibility of the spray system on a hardware item approaching the size of the various SRB hardware, to evaluate the material so applied in a mission exposure simulation, and to demonstrate the removal of the MSA-1, the refurbishment of substrate and the reapplication of MSA-1, simulating one mission cycle. The MSA-1 was therefore applied to one section of the ITB with a design thickness requirement of 3.2 mm (0.12 in.) minimum.

The initial step in substrate preparation was to lightly abrade the Bostik-Finch 443-3-1 white, epoxy topcoat with 100C sandpaper and to remove the dust with a perchloroethylene wipe. The resin tie coat, called the coalescing agent, was then applied; this consisted of two coats of WRD 397 resin, with Shell Z curing agent at the rate of 14 parts per 100 parts resin, reduced to spraying consistency with methylene chloride. The first coat was cured 6 h at room temperature, the second coat cured overnight at 38°C (100°F). The total coating thickness was approximately 0.15 mm (0.006 in.).

The MSA-1 applied was formulated 24-50P (see listing which follows):

	<u>Material</u>	<u>Weight Percent</u>
Solids:	Phenolic Microballoons	37.8
	Silica Microballoons	12.6
	Chopped Fiberglass (1/4 in.)	1.3
	Milled Fiberglass (1/16 in.)	3.1
	WRD 397 Urethane/Epoxy Resin	36.7
	Shell Z Curing Agent	5.1
	Bentone 27	3.4
Solvents:	(per 100 solids)	
	Ethanol	1.7
	Methylene Chloride	~150
	Perchloroethylene	~150

The MSA-1 was mixed and applied using the equipment and procedures established during the development program for this material, requiring approximately 90 min of continuous spraying to cover 11.0 m^2 (118 ft^2) of ITB area plus 5.2 m^2 (56 ft^2) of witness sample spray area. The sprayed material was cured at 38°C (100°F) for 72 h. The cured MSA-1 was then coated with seven coats of Hypalon paint (a chlorosulfonated polyethylene base resin). The applied thickness of MSA-1 and Hypalon was then measured using a Magnetic Reaction Analyzer, in a mode for nonmetallic materials, as a proximity indicator. The analyzer was calibrated with specimens of known thickness and demonstrated a repeatability of 1.5 percent. Measured thicknesses varied from 3.3 to 5.1 mm (0.13 to 0.20 in.) except on the bottom ring where the spray passes were doubled and thicknesses up to 7.1 mm (0.28 in.) were observed. The density and flatwise tensile strength were measured on witness samples attached to and processed with the ITB. The results obtained were 290 kg/m^3 (18 lb/ft^3) and 830 kN/m^2 (120 psi), respectively.

Selected areas of the MSA-1 were then charred using a radiant strip heater thermal source. The heaters were 380 by 584.2 mm (15 by 23 in.) each, and two were mounted together along the 580 mm (23 in.) dimension. The equilibrium heat flux from the heater is approximately 38 kW/m^2 ($3.4 \text{ Btu/ft}^2\text{-s}$); however, this heat flux decays at the edges of the heater due to the viewing angle of the surface and because of the substrate curvature. After applying nominal voltage to the heater, there was no material response other than charring for approximately 90 s. Then blistering of the Hypalon and ignition of the gases generated occurred within 40 s. The burning continued until the heater was deenergized and moved back from the ITB; the burning self-extinguished within approximately 30 s. The Hypalon coating peeled a surface layer of the MSA-1 during the blistering.

Following the flotation tests, handling, and ocean and dockside exposures, the MSA-1 was given a close visual inspection. There was no apparent cracking, delamination, or other degeneration of physical properties in either the charred or uncharred zones. There were a number of gouges and scrapes attributed to handling and shipping, but the damage was not propagated by subsequent water exposure even where the Hypalon coating was penetrated. The flatwise tensile strength of the MSA-1 on the ITB and on controls maintained in dry, laboratory ambient conditions was measured using a Port-A-Pull device. The material on the ITB averaged 380 kN/m^2 (55 psi) with no significant variation from dry, splash, or submerged zones; the controls averaged 420 kN/m^2 (62 psi) when tested with the Port-A-Pull.

The MSA-1 was then removed with the "Hydrolaser," a 62 mN/m² (9000 psi) water impingement device. The Hypalon coating and MSA-1 were readily removed, but the coalescing agent layer was very resistant to the water jet. This problem had previously been observed when the resin was B-staged (cured) too far before application of the MSA-1. A chemical stripper, Cee Bee 8202, was required to remove the coalescing agent.

B. Conclusions

The applicability of the spray process to large-area TPS coverage was demonstrated with excellent results, and the 24-50P formulation was applied without processing difficulties. The material withstood the mission simulation without apparent serious degradation of the mechanical properties.

The most noteworthy problem areas in the application of MSA-1 to large scale hardware identified in the ITB program are:

1. Sensitivity of the water laser removal of coalescing agent to its state of cure prior to MSA-1 application.

2. Difficulty in Hypalon coating application.

In response to the findings on the ITB program, an R&D effort was initiated to find solutions for the most critical problem areas, with the following results:

1. Acceptable MSA-1 adhesion to the epoxy painted substrate is now being obtained without use of coalescing agent, by spraying a more solvent rich formulation. This eliminates any problem in the hydrolaser removal of coalescing agent.

2. Hypalon is no longer used on the MSA-1 topcoat/sealant. Turco 6109, a filled butadiene rubber maskant formulation, was developed in cooperation with the vendor for use as an MSA-1 and cork topcoat. It is readily applied with Nordson hot airless spray equipment and, at a dry film thickness of 9.0 mils, is an effective sealant.

3. Repair techniques for damaged MSA-1 areas are based upon a trowelable ablator formulation, MTA-1, that is similar to MSA-1 except for solvent (i.e., ethanol and freon 113 rather than methylene chloride and perchloroethylene). MTA-1 is also used for closeout applications.

1. The revised procedures omitting coalescing agent, using Turco 6109 as a topcoat, and employing MTA-1 for repairs and closeouts have been repeatedly and successfully demonstrated on test panels prepared for both thermal, physical and environmental tests.

VI. CORK

A. Discussion

Sheet cork applied over structures via a bonding technique has had a long and successful history in aerospace applications as a TPS material. Due to the large area coverage required on the SRB hardware, requiring large amounts of labor manhours for the bonding operation, and the complexity of many of the surfaces to be insulated, cork was not considered a leading candidate material. It was considered a viable backup material, either for selected area coverage on details not suitable for MSA-1 spraying or for general usage (perhaps in conjunction with other materials) should unforeseen problems arise with the MSA-1.

The cork bonding process was therefore demonstrated on the section of the ITB not covered with MSA-1. The substrate preparation, sanding and solvent wiping, was performed as it was for the MSA-1 process, as previously described. The adhesive selected for bonding, RTV-60, was chosen for commonality with the requirements of the silicone foam bonding demonstration (to be described in Section VII). The substrate was primed with Dow Corning 1200 silane primer and the primer aged (hydrolyzed) in accordance with the manufacturer's instructions. The RTV-60 was catalyzed and then spread at a weight of 210 gm/m^2 (approximately 0.008 in.). The cork sheetstock selected was Sheller Globe P-50, 6.35 mm (0.25 in.) thick. This material had given good performance in previous infrared heating tests, aerodynamic heating tests, and thermal/acoustic tests. The sheet cork was bedded on the adhesive and a vacuum bag applied to assure intimate contact over the entire surface area. The pressure differential across the vacuum bag was approximately 100 kN/m^2 (14 psi). The adhesive was cured for 16 h at room temperature before removing the vacuum bag. Two cork areas, each $0.6096 \times 0.6096 \text{ m}$ ($2 \times 2 \text{ ft}$), were prepared.

The P-50 sheet cork was topcoated with the same white Hypalon paint used on the MSA-1; however, unlike MSA-1, only three coats were required to achieve surface sealing. One cork area was then charred using the same radiant heating source as used on the MSA-1. The response to the heating was quite similar. Initially a gradual browning of the coating occurred, followed by blistering, voluminous generation of gases and ignition of the gases, with burning continuing until the heater was deenergized and moved back. The cork then self-extinguished. The Hypalon coating had blistered and sloughed off; the cork

showed a normal char for thermal exposure at one atmosphere air exposure — a fine network of surface cracks with the char well attached. No debonds of the cork were observed.

After the flotation tests, handling and shipping, and ocean and dockside exposure tests, the cork TPS system was given a careful visual inspection. No abnormalities were detected on either the charred or uncharred areas. The attempt to remove the cork TPS system with the Hydrolaser resulted in easy removal of the sheet cork, but the silicone adhesive was very resistant. A chemical stripper, Turco 6045, was used to remove the silicone adhesive.

B. Conclusions

While the Sheller-Globe P-50 cork bonded to substrate with RTV-60 showed no deficiencies in the test, additional work with the bonding procedure has established that TRV-560 is a better adhesive in terms of workability and the results of test specimen exposures in the Tunnel C facility at the Arnold Engineering Development Center, Tullahoma, TN, and in the MSFC Modified Hot Gas Facility have shown no deficiencies in the bonding procedure using RTV-560.

Hypalon is no longer used on cork as a topcoat/sealant. As with MSA-1, Turco 6109 is now the accepted formulation. It is readily applied to the desired film thickness and has proven very effective.

VII. SILICONES

A. Discussion

A companion material to the sheet cork discussed in Section VI is the silicone foam sheetstock material, available from General Electric Company as PD200-16. This soft, compliant open-celled foam with a nominal density of 260 kg/m^2 (16 lb/ft^3) can be used on surfaces with moderate double curvature or over very short radii and complements the cork sheetstock which is most usable for surfaces of single curvature and longer radii. As in the case of MSA-1 and cork sheetstock, the performance of the material had been previously demonstrated in a series of thermal exposure tests with successful results. It was therefore highly desirable to demonstrate the bonding process integrity and to investigate the performance of the PD200 in a mission simulation on the ITB.

The bonding process for PD200 was identical to that used for cork (described in Section VI.A.) up to the point of bedding the insulation on the spread RTV-60 adhesive. The insulation was 6.35 mm (0.25 in.) thick PD200-16 which had been surface sealed with General Electric RTV-560 in an 0.2 mm (0.008 in.) layer. It was rolled down onto the adhesive and again vacuum bagged; however, the vacuum bag differential pressure was limited to 3.447 kN/m^2 (0.5 psi) to prevent excessive flattening of the foam and penetration of the adhesive into the open-cell structure which would prevent springback of the foam upon pressure release.

Following the bonding operation, the PD200 was coated with Dow Corning 92-007 white silicone paint to achieve the desired surface color. The applied coating thickness was approximately 0.07 mm (0.003 in.). As in the case of the cork, two areas, each $0.61 \times 61 \text{ m}$ ($2 \times 2 \text{ ft}$), were prepared.

One area of PD200 was then charred using the apparatus and techniques previously described. While slight differences in the time of occurrence were noted, the general course of browning, charring, ignition of gases, burning, and self-extinguishing is essentially the same in PD200 as observed with MSA-1 and cork. Due to the poor simulation of any actual flight thermal environment, possible errors in the setup of the radiant source, and the variations possible in local wind speed (convective cooling), no particular significance is attached to these time differences. The PD200 exhibited a normal, air-environment thermal test char with loose, fluffy deposited silica over a stable char.

Following the mission simulation exposures, the PD200 was visually inspected. No abnormal conditions or potential problems with the material or bonding system were observed. The PD200 foam was removed with the Hydro-laser without difficulty. The RTV-60 adhesive was again removed with Turco 6045 stripper.

B. Conclusions

The General Electric PD200-16 silicone sheetstock bonded with RTV-60 adhesive by the process used and with DC92-007 topcoat gave excellent performance in this test. The major deficiencies observed in this test are the relative slowness of the bonding operation for area coverage and the difficulty of adhesive removal for refurbishment. Other conclusions are as follows:

1. As in the case of Cork, RTV-560 has proven to be a more workable adhesive than RTV-60, with no sacrifice in performance.
2. Investigations have been undertaken to develop a silicone adhesive system which is removable with the Hydrolaser, but no acceptable system has yet been found.
3. Other investigations have shown that residual RTV-560 is not detrimental to further bonding operations with RTV-560, except that repeated bonding operations without adhesive removal will build a thick adhesive layer with a weight penalty.
4. For surfaces of simple geometry, "wallpaper" bonding techniques can be used to avoid the use of the vacuum bag, greatly increasing the speed of coverage where this technique can be used.
5. Silicone foam insulation material very similar to PD200-16 can be applied by a spray system developed under contract NAS8-32136 with General Electric. While this material is attractive from the speed of coverage aspect, it has a substantial material cost penalty compared to MSA-1 with quite similar performance.
6. Also under contract NAS8-32136, the fabrication and bonding of molded PD200-16 detail parts were demonstrated. The utility of such parts for the insulation of very complex details is under review.

VIII. MATERIAL BIODEGRADATION ASSESSMENT

A. Panel Specimen Exposure

The environmental assessment testing of materials in a marine environment began in 1972 in the Gulf of Mexico at Panama City, Florida. Two material panels racks were used in this testing. Each rack measured 1.22×1 m (4×3 ft) and accommodated 20 panels [12 single panels, 10×15 cm (4×6 in.) and 8 composite panels, 10×25 cm (4×10 in.)]. One material panels rack was located 3.048 m (10 ft) below the surface of the water (low tide), attached to the Navy's Stage II oceanographic platform. The other material panels rack was placed 3.048 m (10 ft) below the surface of the water at the estuarine location near the Navy Coastal Systems Laboratory. As a result of severe weather conditions, the rack in the Gulf waters was completely broken up and lying 18.288 m (60 ft) down on the ocean floor when recovered. The panel in estuarine waters remained in place for the duration of the tests.

Tables 7 and 8 list the environmental condition under which each test was made.

Biodegradation testing was begun in SRB recovery waters of the Atlantic Ocean approximately 16.093 km (10 miles) offshore at KSC on November 25, 1975. This test vehicle (test rack) was lost at sea and found January 22, 1976 on Melbourne Beach, Florida.

A duplicate test rack was anchored 64.8 m (700 yd) offshore at KSC on January 12, 1976. Water depth at this position was 7.6 m (25 ft). The test rack was held at splash level by buoys (Table 8). Thirty-two metal test panels were fastened to this rack; the first row of eight panels, 10×18 cm (4×7 in.), were used for biodegradation testing (Figs. 33 and 34). Assembly of both coated and uncoated panels used in the biodegradation testing is shown in Figures 35 and 36. In addition to the specimen panels fastened to the test rack, four specimen panels were suspended from the test rack, two at a depth of 1.0 m (3.28 ft) and two at a depth of 2.4 m (8 ft). One coated panel and one bare metal panel were used at each depth.

TABLE 7. OCEANOGRAPHIC AND CHEMICAL DATA DURING
BIOLOGICAL ASSESSMENT — GULF OF MEXICO

Temperature (February 17-25, 1972): 56°F — Bay

Temperature (February 17-25, 1972): 59 to 60°F — Gulf

Salinity (TP 161): 18 to 20 ppt — Bay

Salinity (TP 161): 32 to 36 ppt — Gulf

Dissolved O₂ concentration (O₂/salt H₂O) (measured late August 1959):
3.71 ml/1 (72.5%) to 4.58 (88.5%) — Bay (surface)

Dissolved O₂ concentration (O₂/salt H₂O) (measured late August 1959):
2.90 ml/1 (59.2%) to 3.93 (80.6%) — Bay (bottom)

Dissolved O₂ concentration (O₂/salt H₂O) (per discussion — Schuh and
Howard February 1972): $\cong$ 4 ml/1 (O₂/salt H₂O) — Gulf

pH (per discussions — February 1972): $\cong$ neutral to $\cong$ 7.0 — Gulf

Visibility (TP 161): $\cong$ 8 m (April and October) minimum — Gulf

Visibility (TP 161): $\cong$ 15 m (August - September) maximum — Gulf

Specific gravity seawater (TP 161 given salinity, temperature
1.0235 gm/cc and atmospheric pressure, Ref. — distilled
H₂O, 4°C)

Surface current velocity — Average February (TP 161): 0.35 kn —
Gulf

Surface current velocity — Maximum February (TP161): 0.5 kn —
Gulf

Bottom current velocity — Average February (TP 161): 0.14 kn —
Gulf

Bottom current velocity — Maximum February (TP 161): 0.3 kn —
Gulf

TABLE 8. OCEANOGRAPHIC AND CHEMICAL DATA DURING
BIOLOGICAL ASSESSMENT AT KSC (JANUARY 12-30, 1976)

Testing Sites:

- Oceanic — Atlantic Ocean, 64.8 m (700 yd) offshore; position
28°36'08"N, 80°34'47"W in 7.6 m (25 ft) of water.
- Port — Banana River in a restricted area immediately north of
NASA Causeway, under Banana River Bridge in 3.6 to
4.6 m (12 to 15 ft) of water.
- Dock — Banana River, adjacent to Hangar AF. Test subjects were
suspended from the NASA barge anchored here.

Testing Protocol: Test rack in water at splash level

First Exposure

- Ocean — 9 days (transport test rack aboard ship to port site)
- Port — 24 h (transport by truck to cleaning site)
- Return test rack to ocean site

Second Exposure

- Ocean — 4 days (transport by ship to port site)
- Port — 24 h (transport by truck to Operations Checkout
Building and disassemble). The 8 biological panels
were returned to MSFC. Selected panels of remaining
24 panels were exposed to natural environment at
beach.

Biodegradation Test Panels:

Coated Panels

- Base metal — 2219-T87 aluminum, 7075T651 aluminum
- Fasteners — 286 stainless steel
- Primer — Bostik 463-6-3

TABLE 8. (Continued)

Sealants —		
<u>Panel No.</u>	<u>Sealant No.</u>	<u>Sealant Type</u>
188	1	PR 1422B2
126	2	PR 1201HT
104	3	PR 1431G
137	4	PR 1223B4
190	5	PR 1750B4
165	6	230 Grey (PRC)
42	7	890B4 (Seal PAK)
19	8	DC 93-076

Topcoat — Bostik epoxy 443-3-1

The aforementioned coated panels were not heat treated.

Uncoated or Bare Metal Panels

Base metal — 2219-T87 aluminum, 7075T651 aluminum, 7075T756 aluminum with a flange ($5 \times 8 \times 0.32$ cm) ($2 \times 3 \times 1/8$ in.) of D6AC steel.

Fasteners — 286 stainless steel

Size without flange — 10×18 cm (4×7 in.)

In addition, one disassembled coated panel in three parts and of unknown coating type was used in dock water testing.

Test Requirements for Panels:

Test rack — Accommodated four rows of eight panels each. The first row was biodegradation test panels:

Panel No. 118 — uncoated

165 — coated

42 — coated

104 — coated

137 — coated

190 — coated

126 — coated

183 — uncoated

TABLE 8. (Concluded)

Four panels were hung from the rack —

Panel No. 118 (coated)	— 2.4 m (8 ft)
112 (uncoated)	— 2.4 m (8 ft)
19 (coated)	— 1.0 m (3 ft)
116 (uncoated)	— 1.0 m (3 ft)

The test rack was used in oceanic and port testing.

Barge or dock testing —

Panel No. 62 (uncoated)	— 2.4 m (8 ft)
180 (uncoated)	— 1.0 m (3 ft)
117A (coated)	— 0.6 m (2 ft)
117B (coated)	— 1.0 m (3 ft)
117C (coated)	— 2.4 m (8 ft)

The dock test water was considered a worse case.

A 2 day delay in recovery was experienced due to severe weather conditions. The specimen panels which had been suspended 2.4 m (8 ft) were lost at sea. When the sample rack was brought aboard ship, photographs were made and culturing of marine organisms was begun immediately. Ocean water samples were collected for return to MSFC. The seawater temperature at this site was 14°C (57°F).

The test rack was transported aboard ship to a restricted area immediately north of the NASA Causeway under the Banana River Bridge which simulated port waters (Fig. 37). The water depth in this area was 3.7 to 4.6 m (12 to 15 ft). The water temperature was 15°C (59°F).

After 24 h the test rack was recovered from the Banana River Bridge site, cultures were made, and the rack was transported to the KSC cleaning area. The rack of panels was cleaned in accordance with MSFC cleaning procedures and returned to the ocean site the following day. Test protocol required 5 additional days of exposure. During the night of January 27, 1976, the test rack broke loose from the buoys and was found on shore at KSC the following morning (Fig. 38). No cultures were taken of the dry rack. The test rack was taken to the Banana River port site for the 24 h exposure test. At the

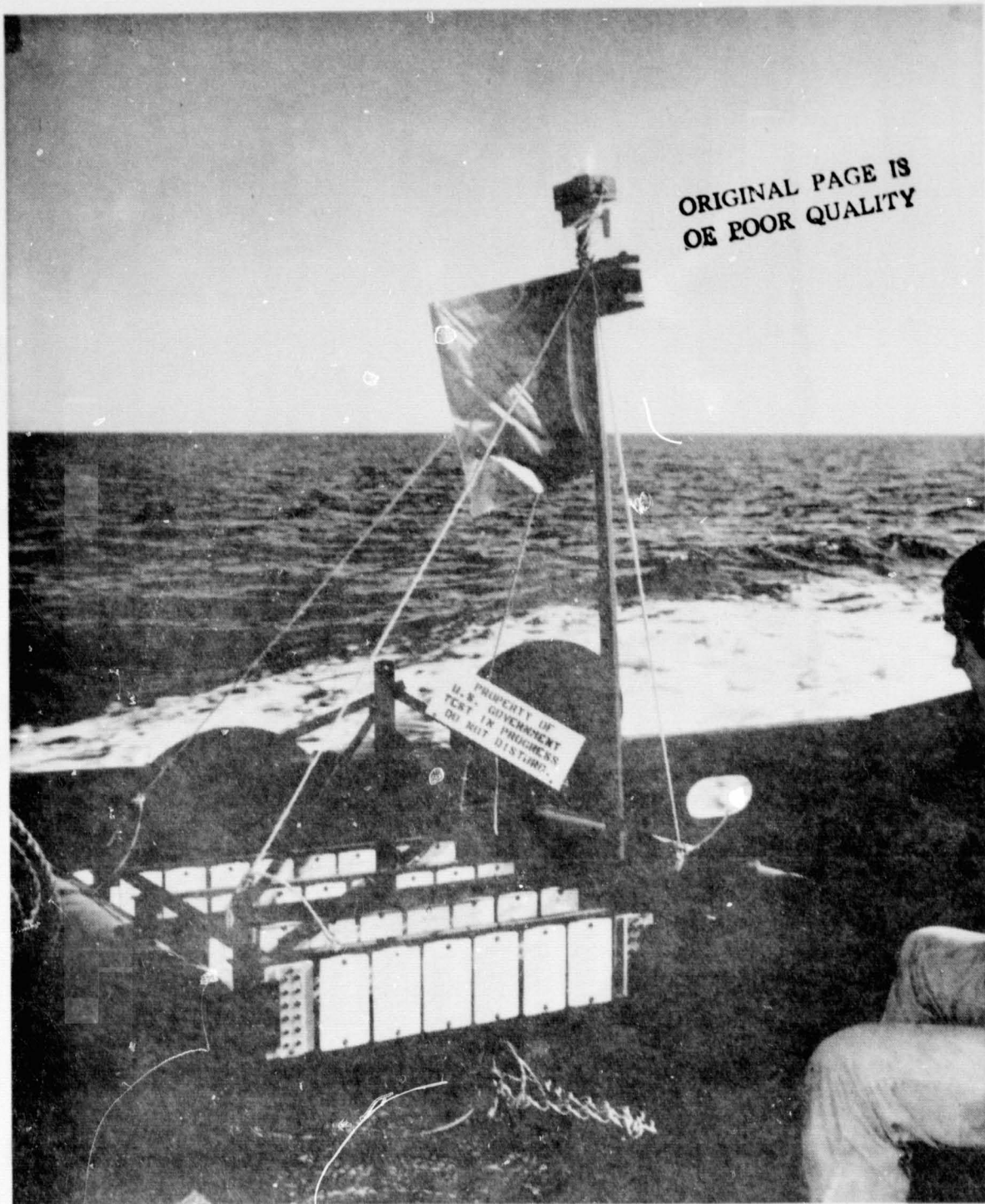


Figure 33. Test panels rack.



Figure 34. Sample rack test, site No. 2.

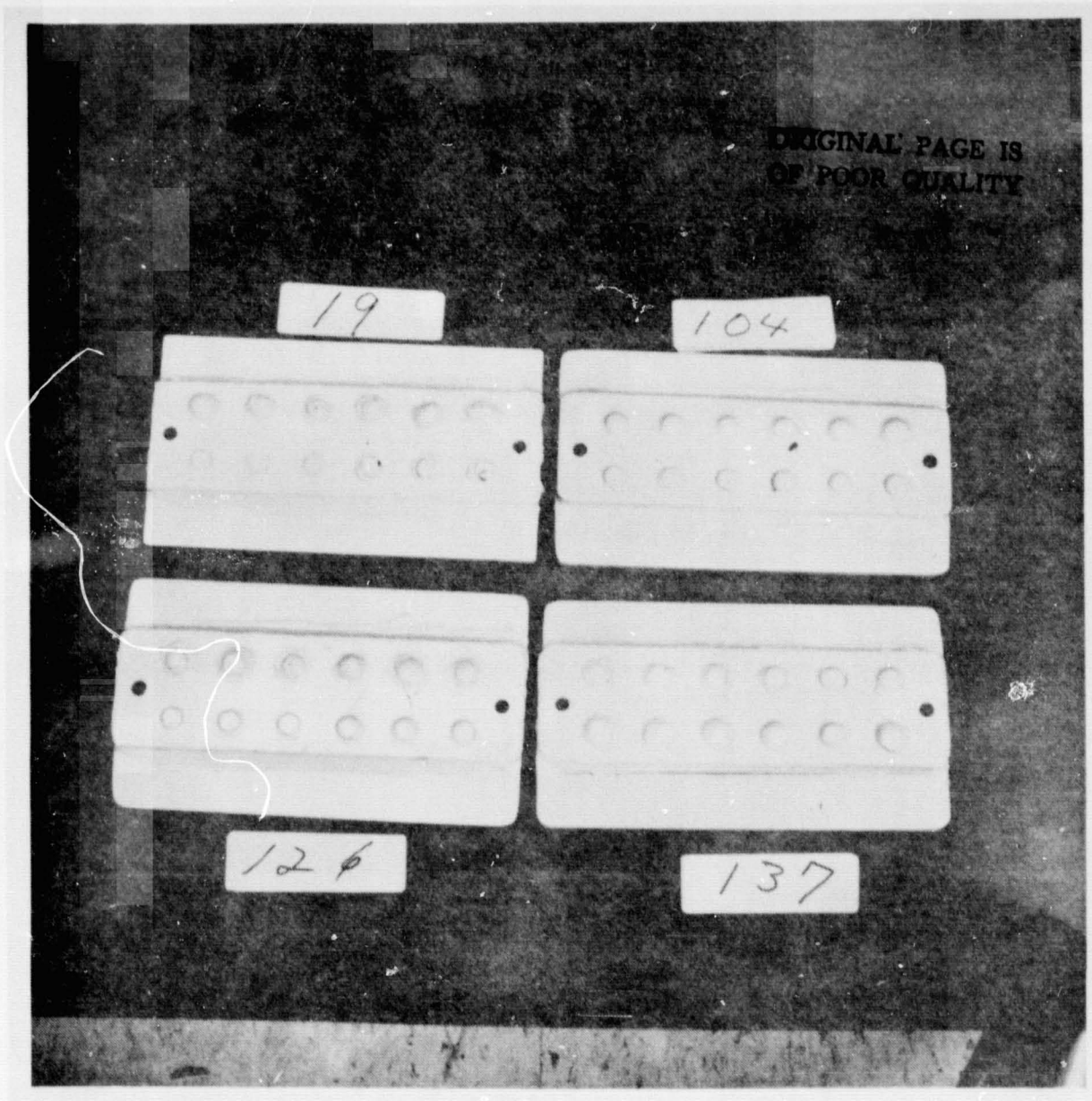


Figure 35. Coated sample panels (before testing).

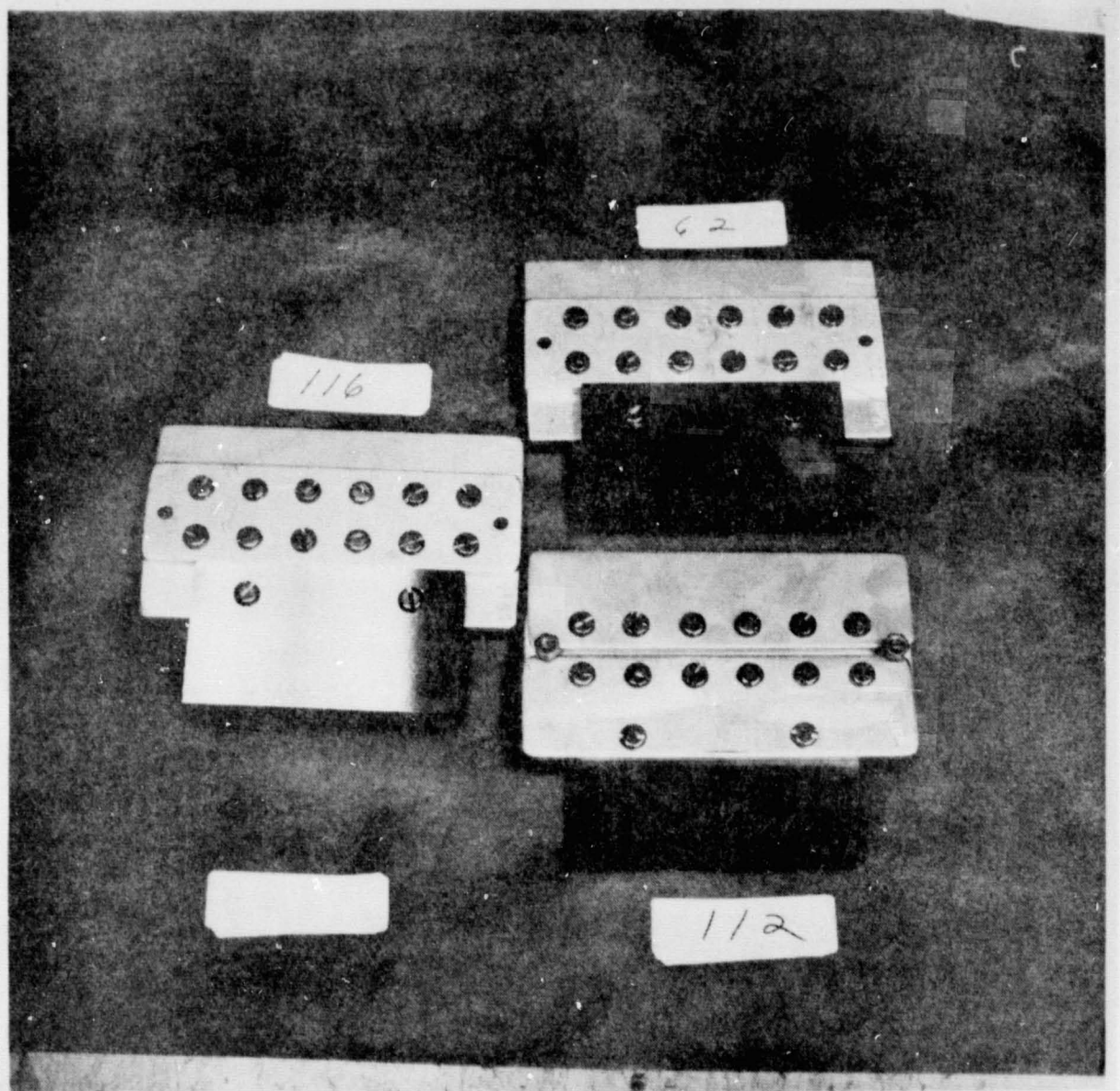


Figure 36. Uncoated sample panels (before testing).



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Figure 37. Port water test site.

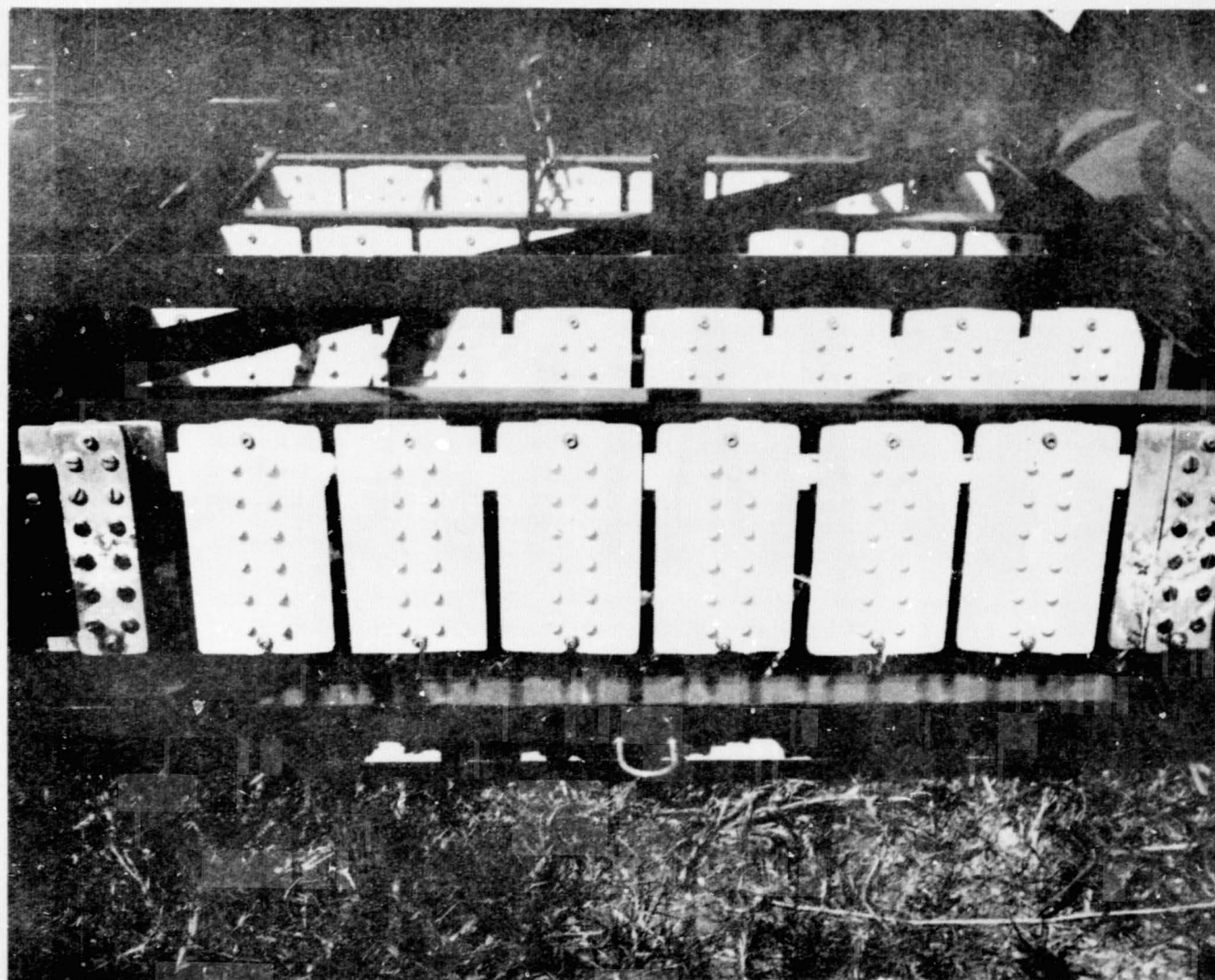


Figure 38. The test rack after washing ashore during the night of January 27, 1976 (recovery was scheduled for January 28, 1976).

completion of this test, the rack was moved to the KSC Checkout and Operations Building where the biodegradation panels were removed, photographed, and sealed in ziplock bags for return to MSFC. The two panels which had been suspended from the test rack were returned to MSFC in separate containers of river water.

B. Dock Site Testing

Dock site testing, off the NASA barge anchored opposite Hangar AF, began on January 16, 1976 (Fig. 39). Figures 40 through 51 show results of exposure in dock site waters. Photographs were made at 72 h, 120 h, 143 h, 240 h, 288 h, and 332 h. Two of these panels were removed and returned to MSFC for assessment after 143 h of test, and all panels were returned to MSFC on January 30, 1976.

The dock site water is considered a "worse case" for microbial growth. The waters are brackish, containing a mixture of inland and ocean waters. However, the water collected from this site is considered "surface" type water because at present the channel is not deep enough to accommodate an ocean recovery vessel. This channel will be dredged prior to Shuttle launch creating a new water environment. Also the turbulence of the SRB tow operation will necessitate assessment of the deeper water and the sediment to ascertain what environment will affect the SRB.

C. In-House Assessment of Sample Panels

In the laboratory testing, pure cultures were isolated from the broth and agar petri plates onto the appropriate agar. The Shewan scheme of differentiation was used for microbial general identification. Table 9 presents a summary of the test used in the determinative scheme and shows the determinative groupings.

D. ITB Exposure

The ITB was anchored in the Atlantic Ocean test site off KSC on June 4, 1976, for a 5 day exposure test (Table 10, Fig. 52). Samples representative of materials contained in the ITB were prepared for biodegradation testing. These samples were attached to an angle iron sprayed with primer paint. Teflon strips

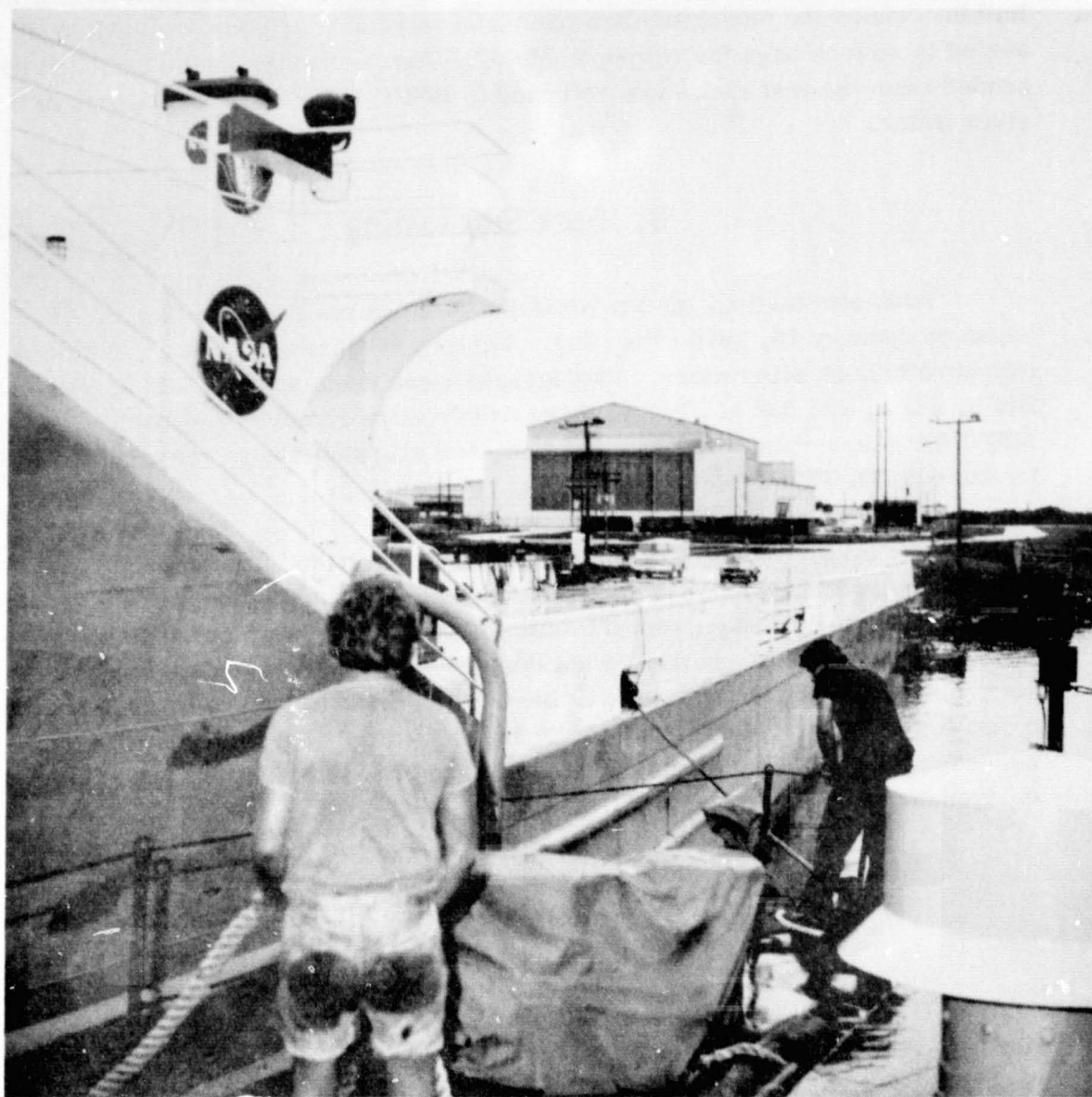


Figure 39. SRB recovery site used for sample dock site testing.

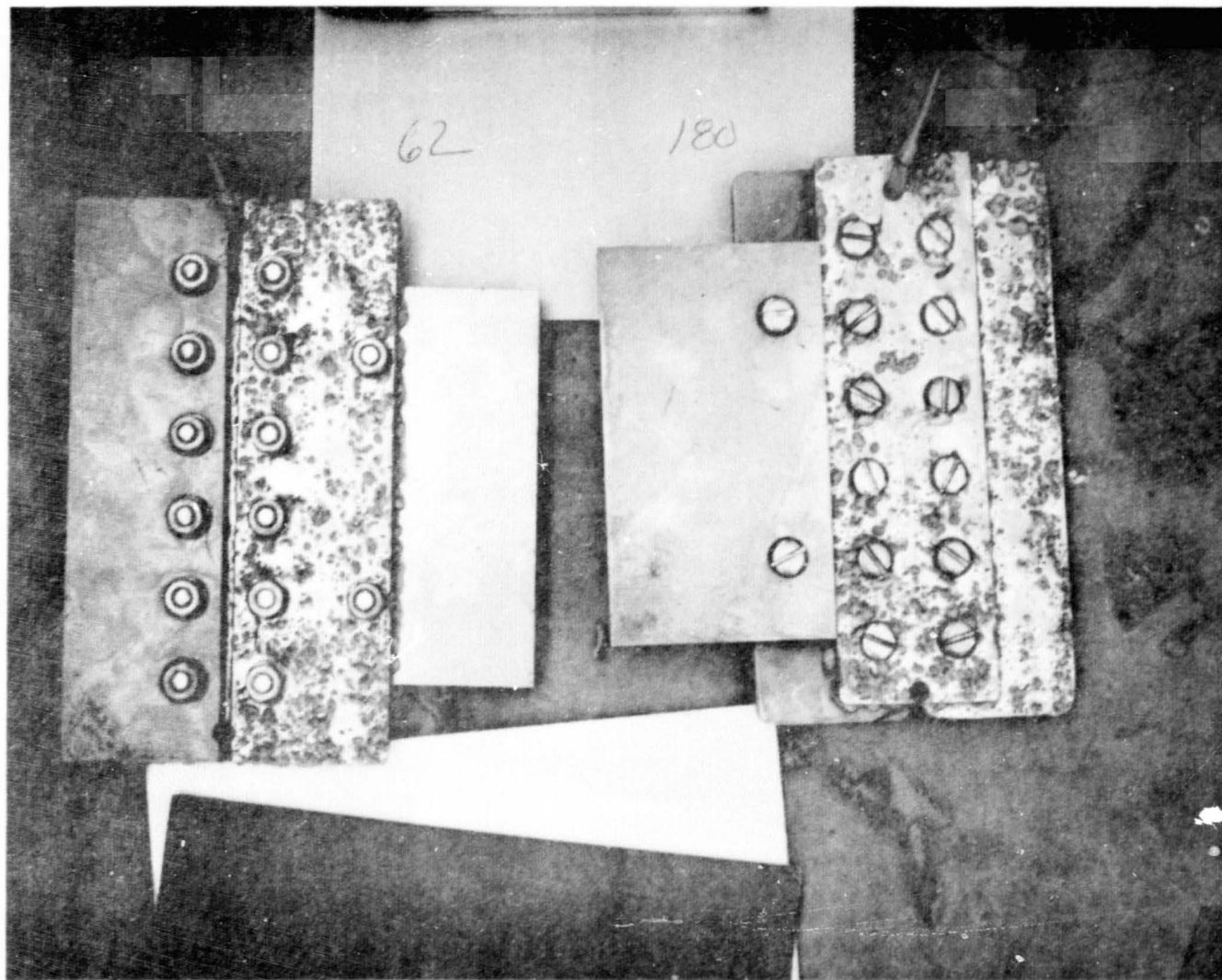


Figure 40. Uncoated panel Nos. 62 and 180 after 72 h in dock site water (No. 62 in 8 ft of water; No. 180 in 3 ft of water).

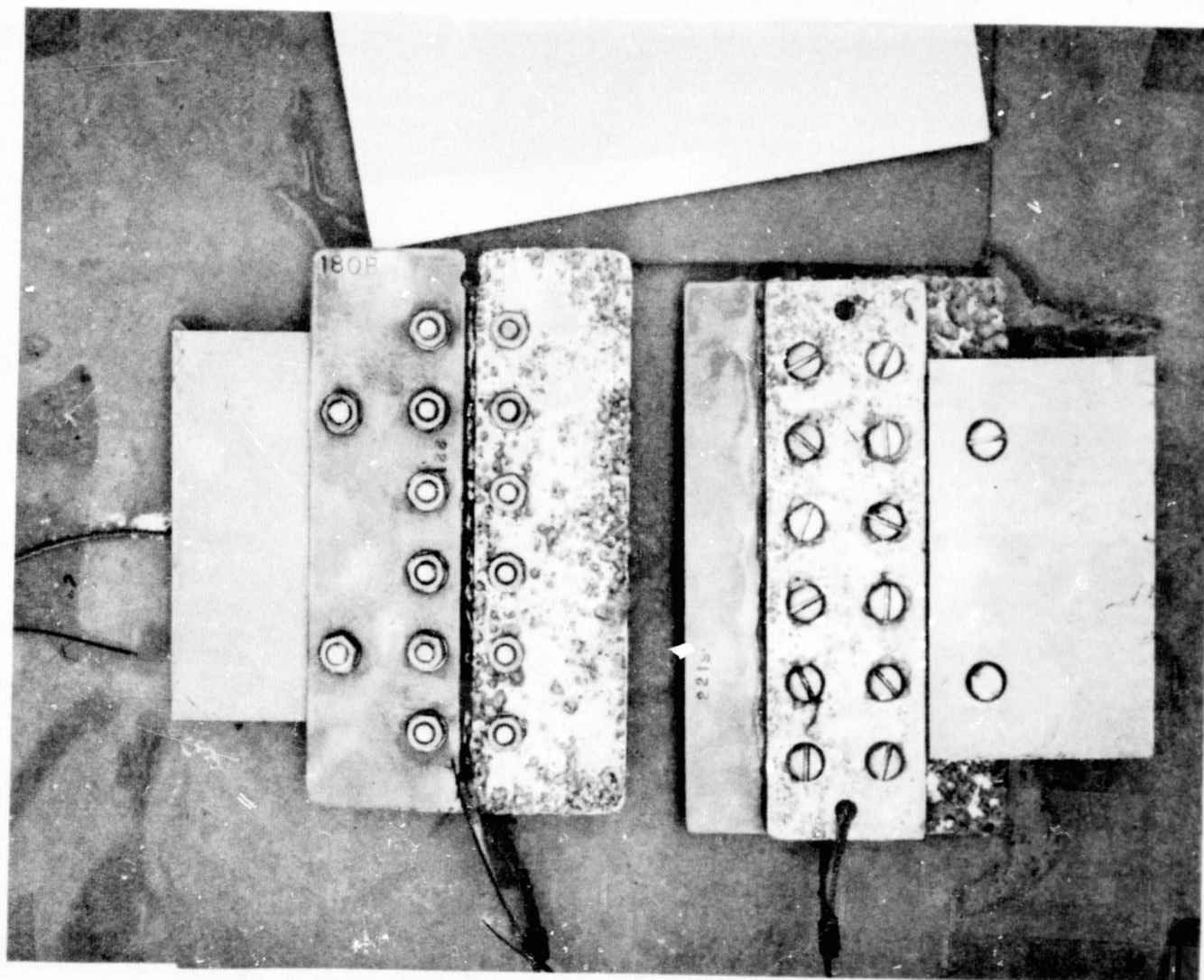


Figure 41. Opposite side of uncoated panel Nos. 62 and 180 after 72 h in dock site water.

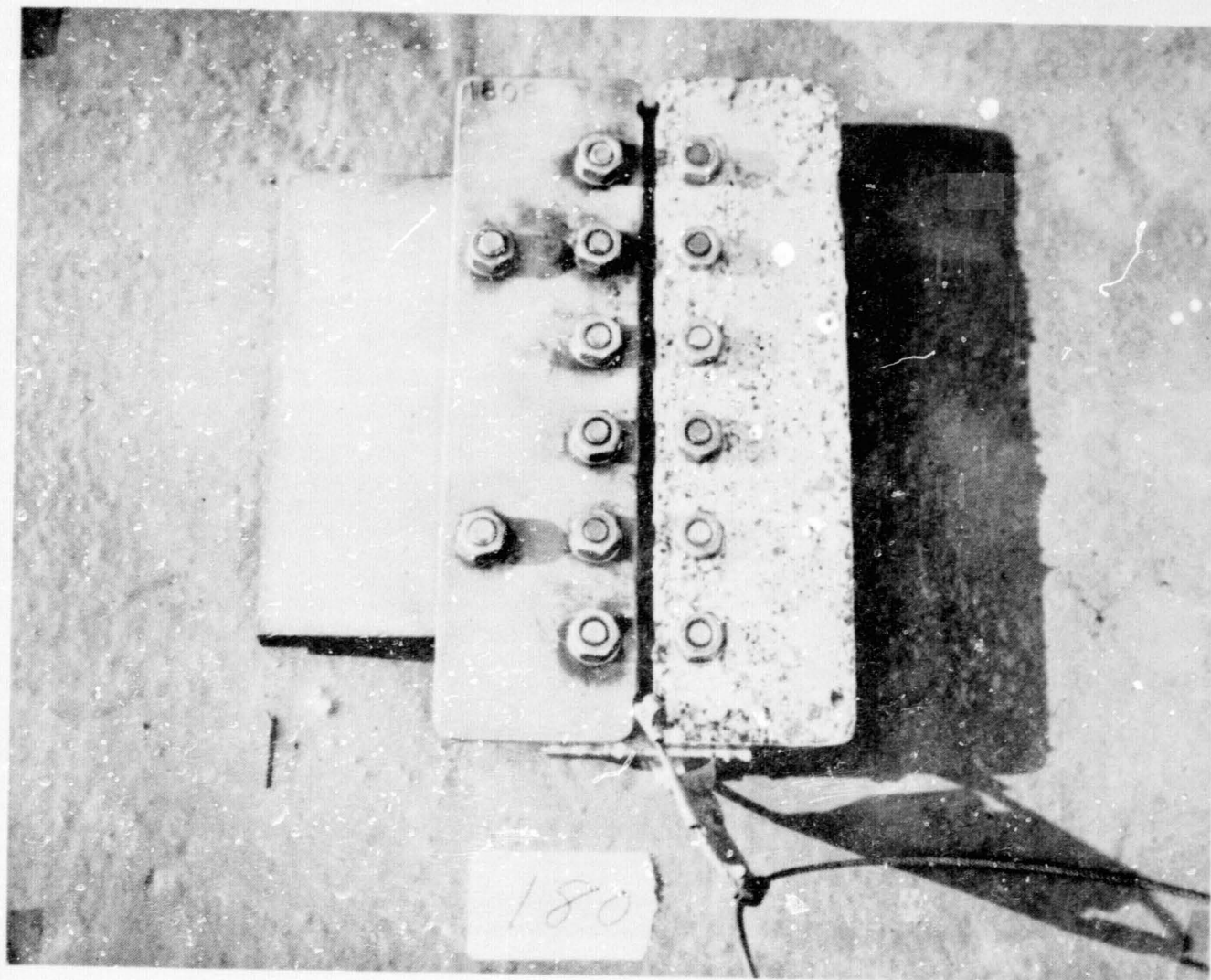


Figure 42. Uncoated panel No. 180 after 240 h in dock site water at 3 ft.

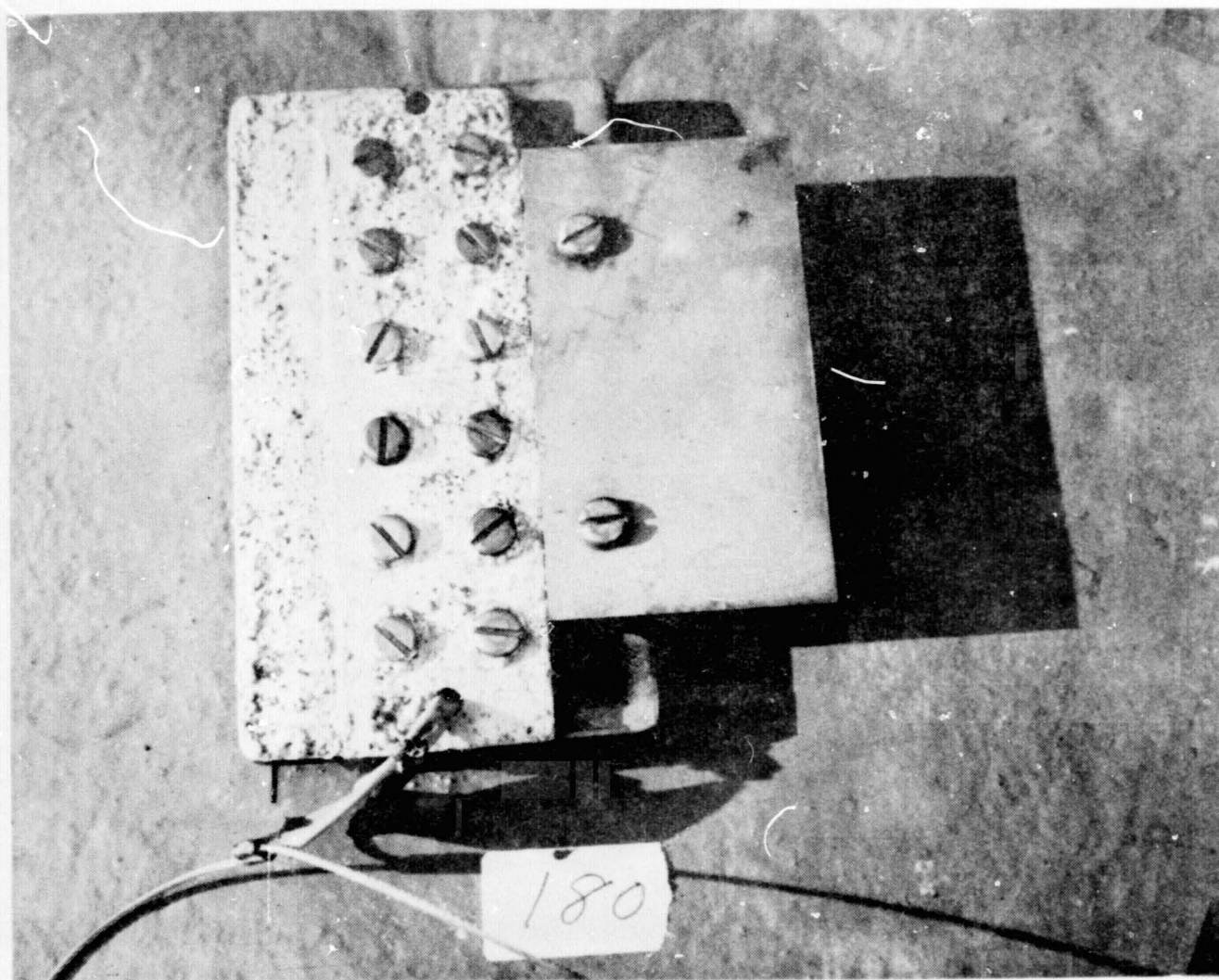


Figure 43. Opposite side of panel No. 180 after 240 h in dock site water.

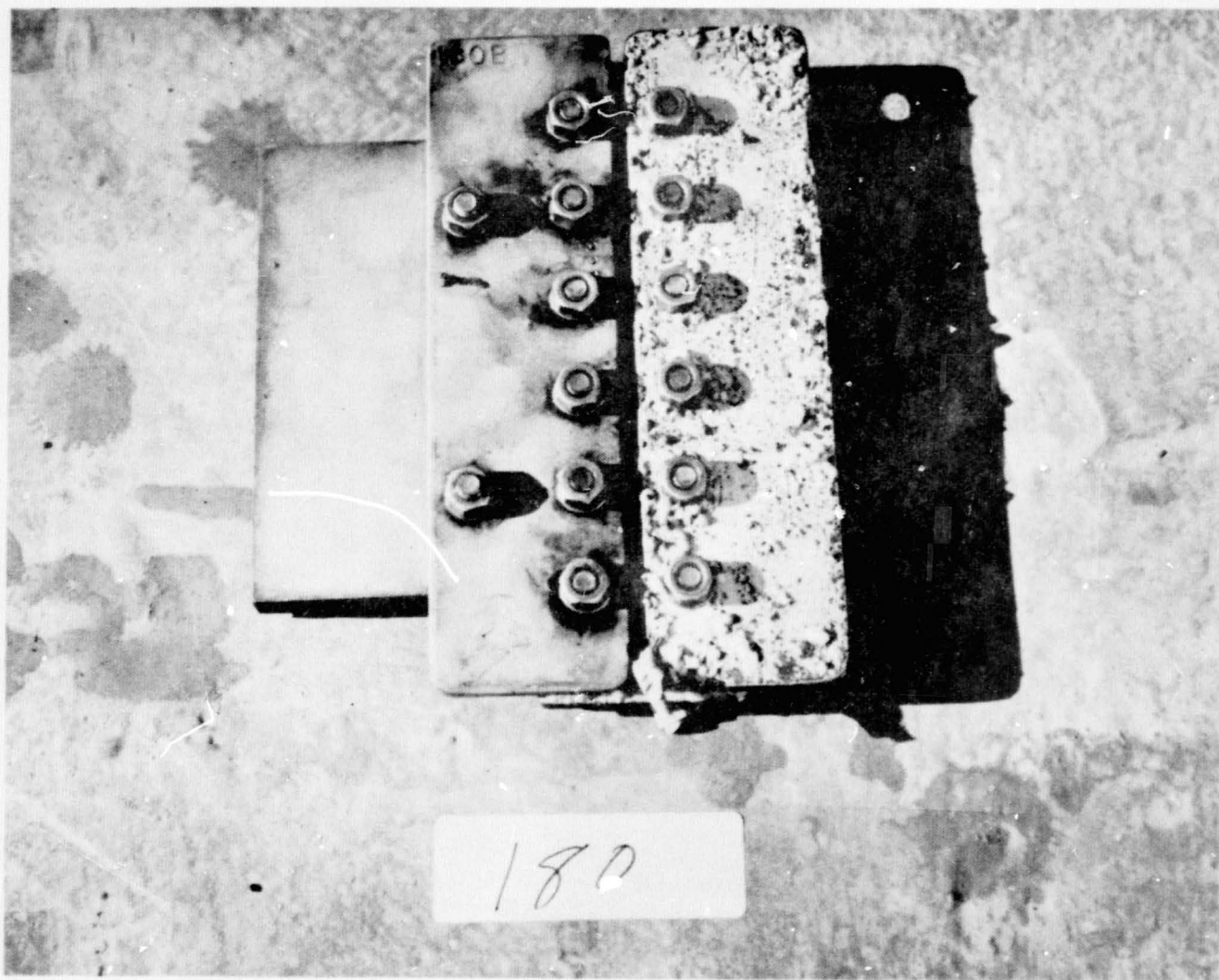


Figure 44. Uncoated panel No. 180 after 332 h in dock site water at 3 ft.

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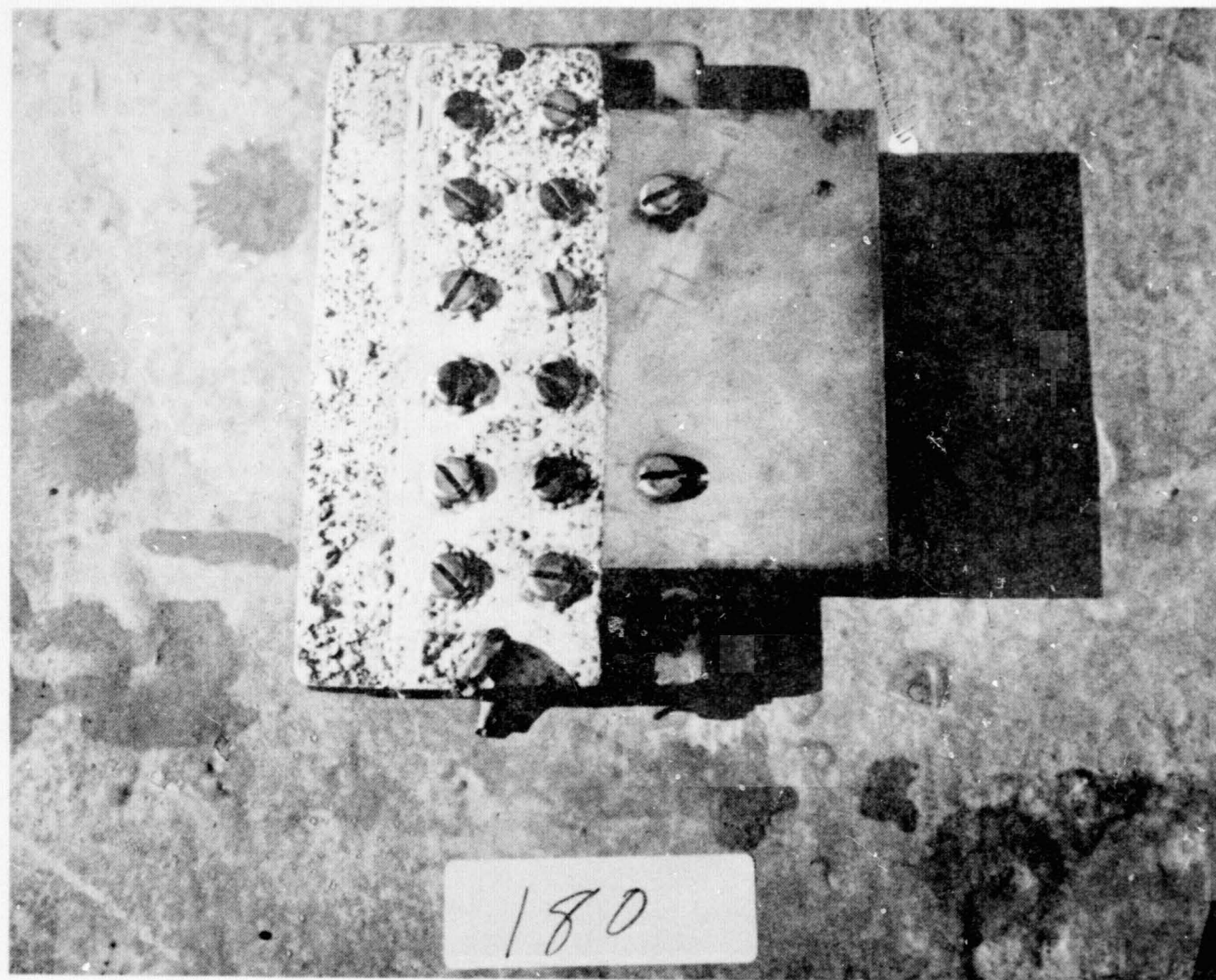


Figure 45. Opposite side of panel No. 180 after 332 h in dock site water.

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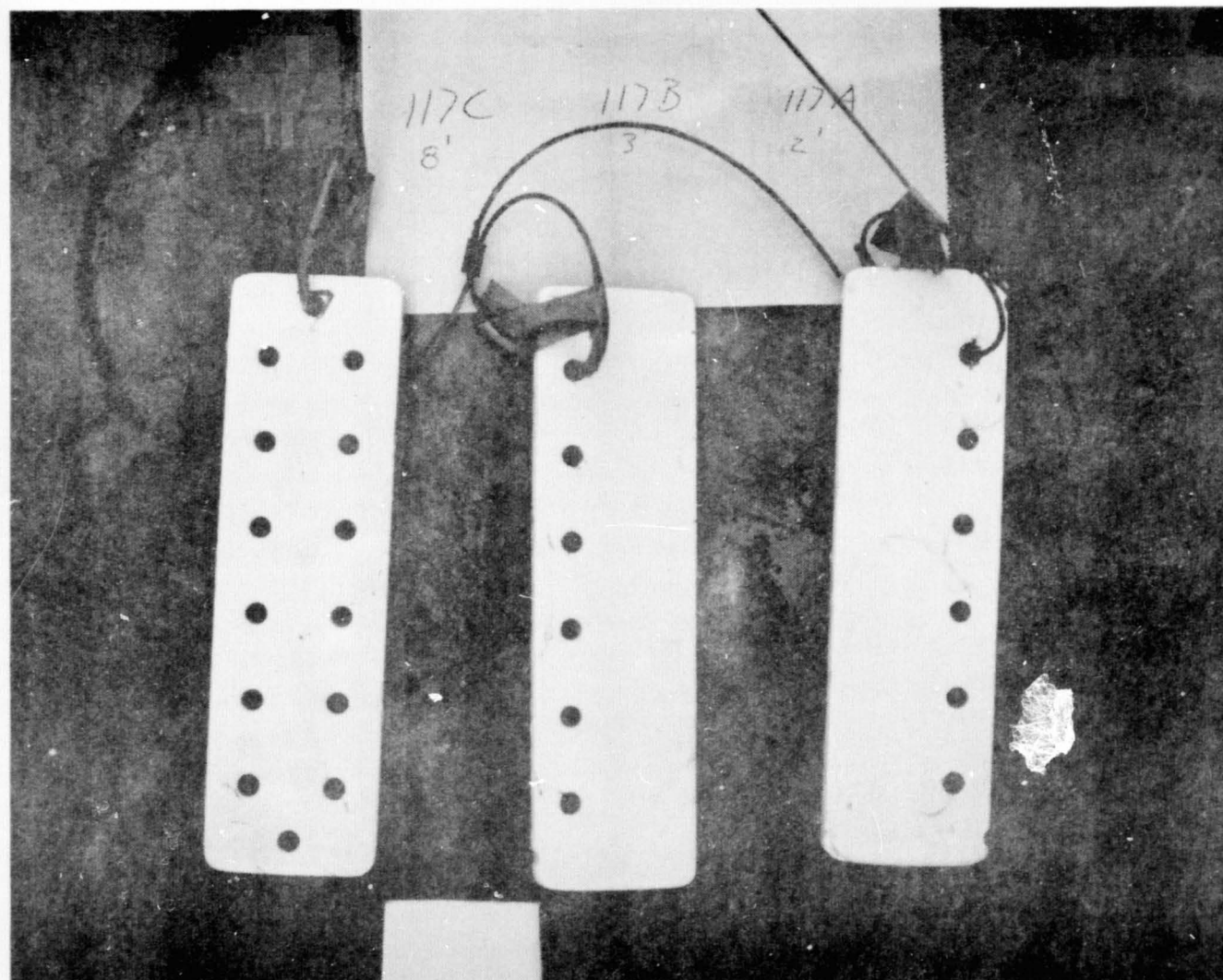


Figure 46. Panel parts 117A, 117B, and 117C after 72 h in dock site water. (Depths are noted below panel numbers. Panel 117A consistently held marine buildup.)

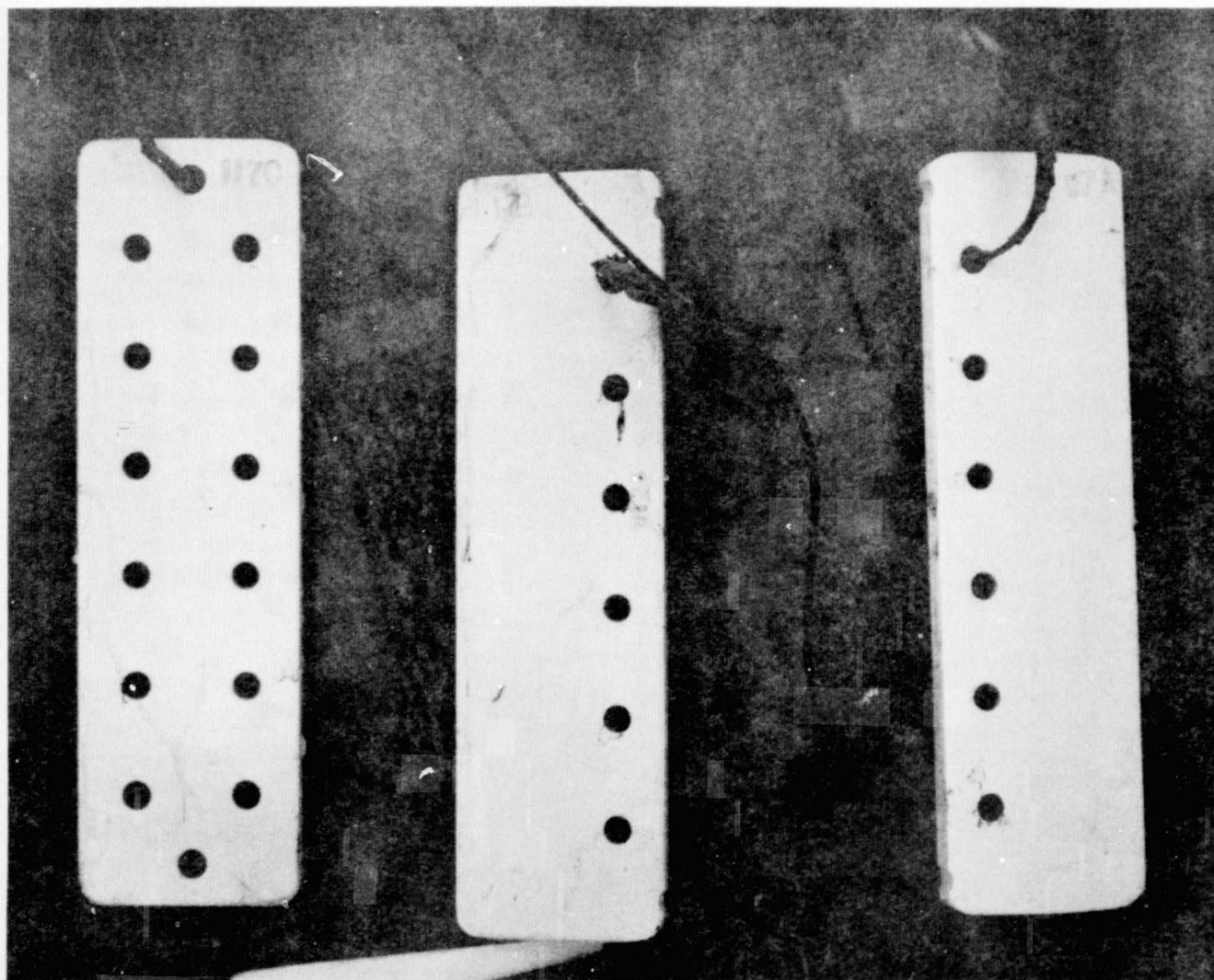


Figure 47. Opposite side of panel parts 117A, 117B, 117C (right to left) after 72 h.

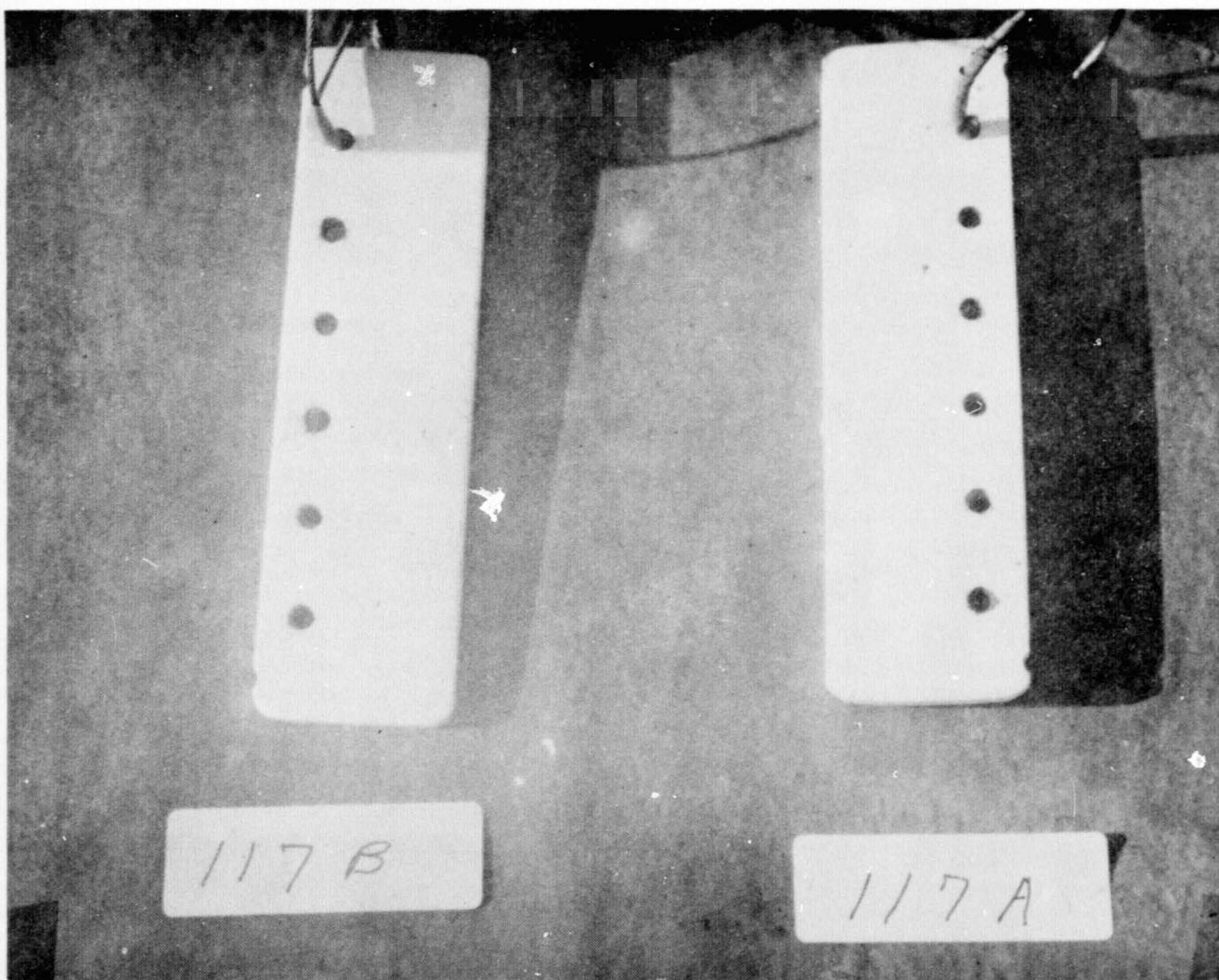


Figure 48. Panel parts 117A and 117B after 240 h in dock site water.

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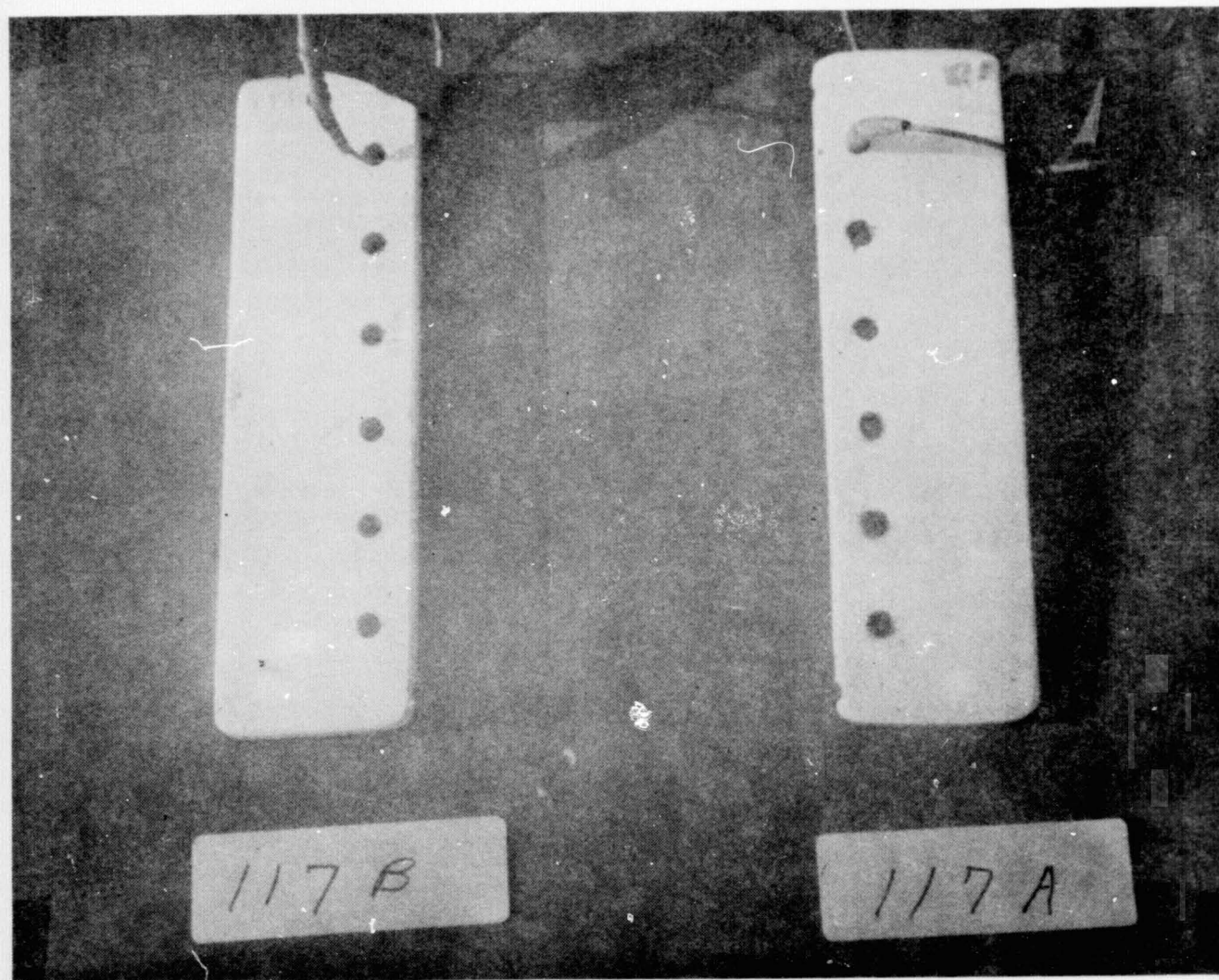


Figure 49. Opposite side of panel parts 117A and 117B after 240 h in dock site water.

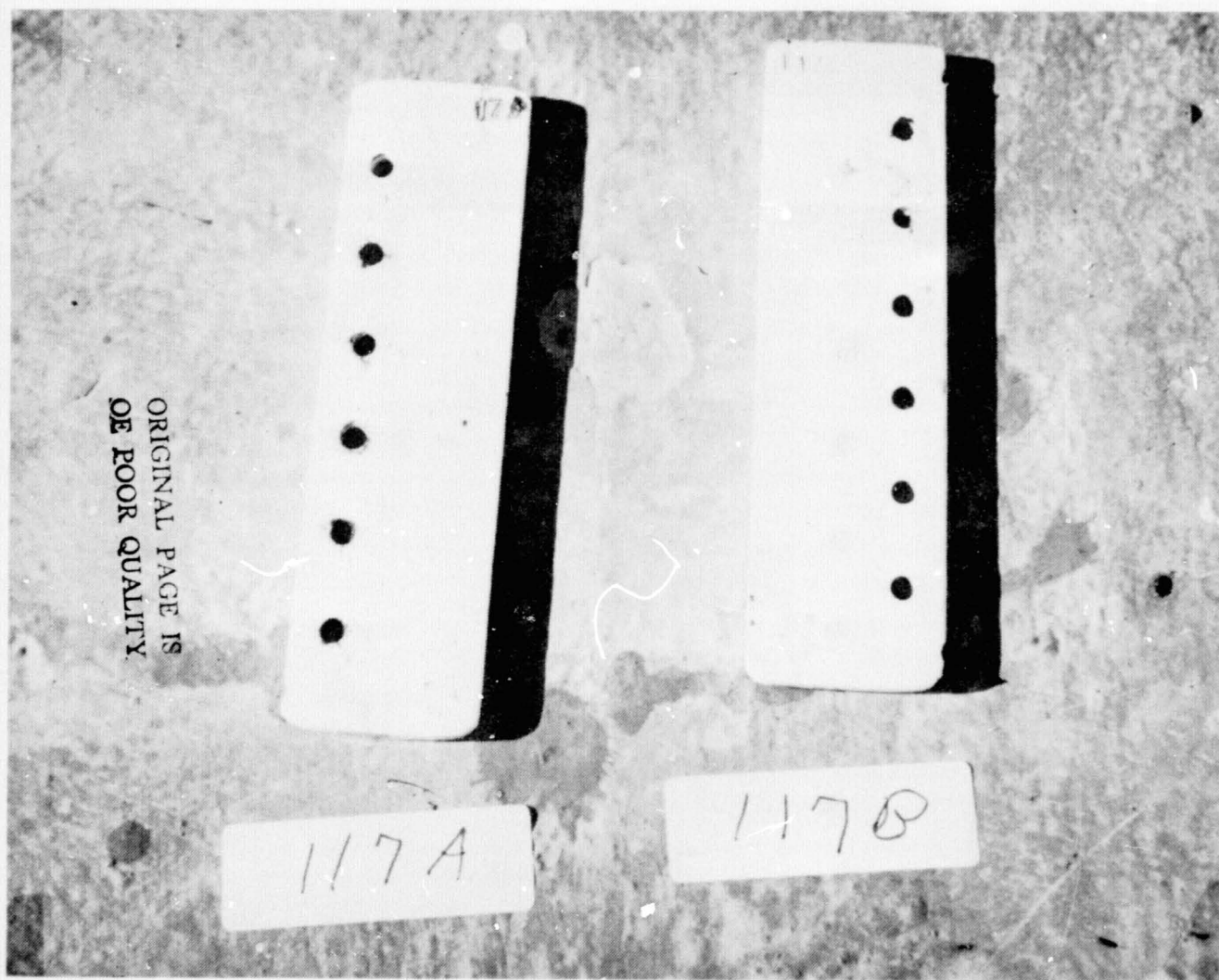


Figure 50. Panel parts 117A and 117B after 332 h in dock site water.

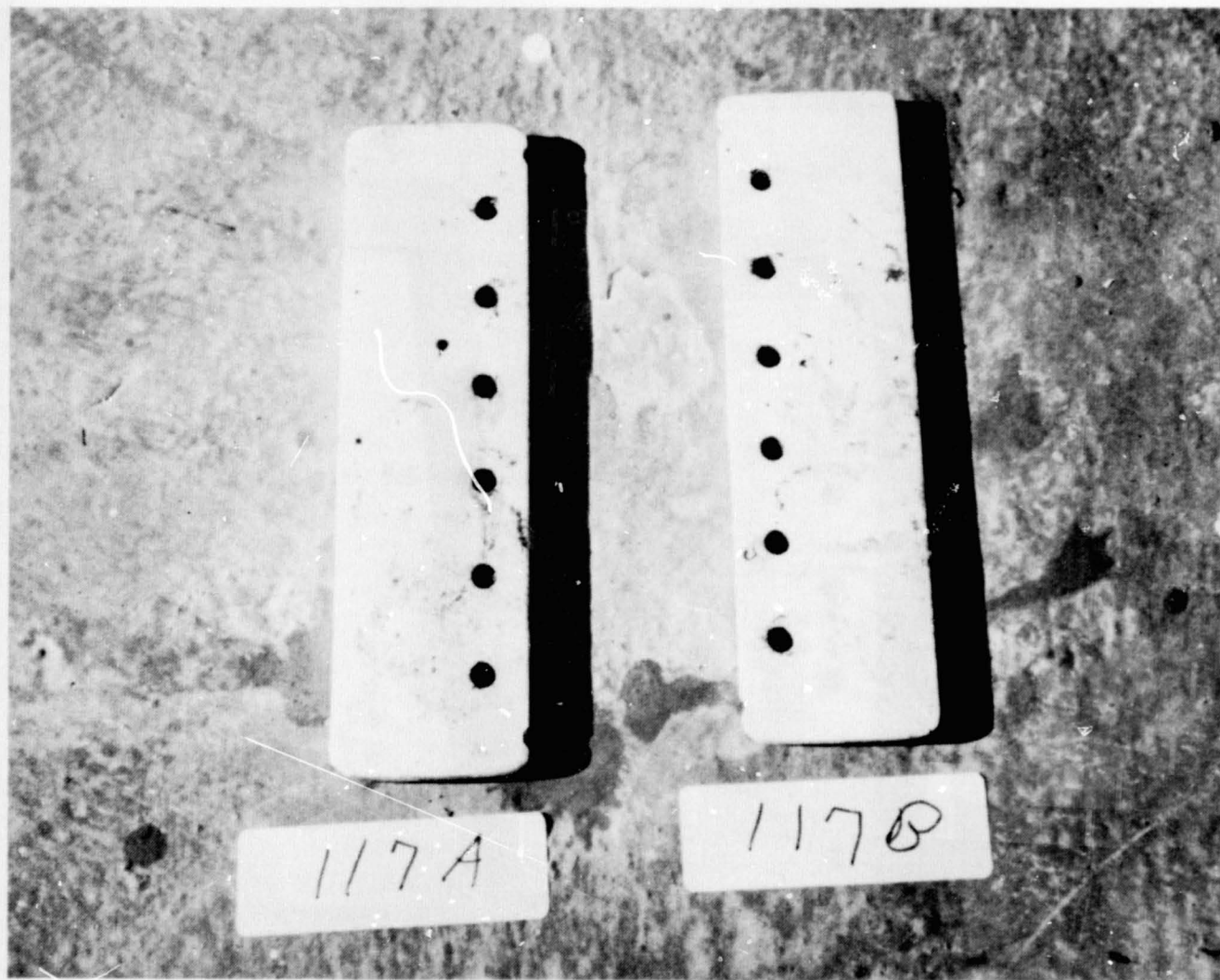
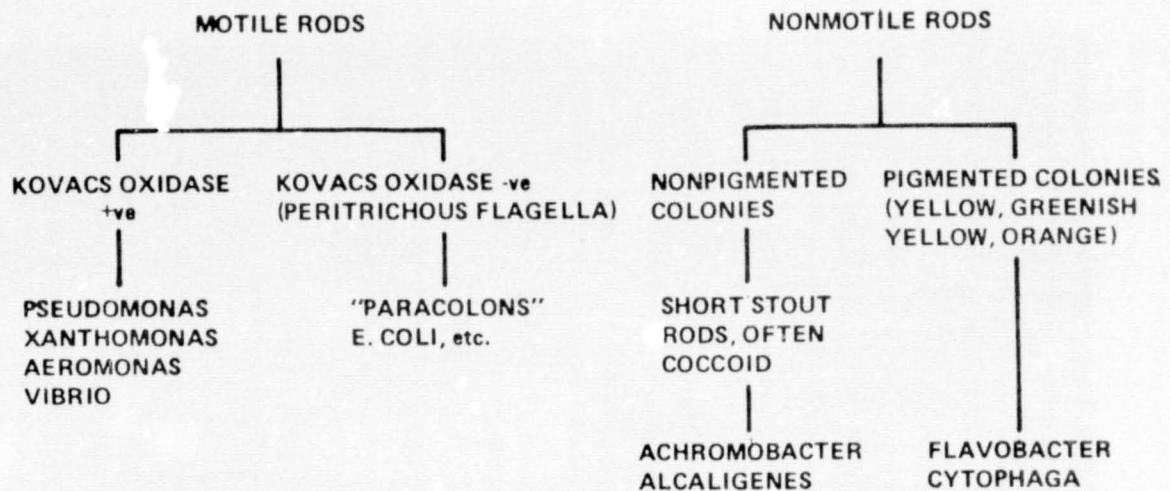


Figure 51. Opposite side of panel parts 117A and 117B after 332 h in dock site water.

TABLE 9. SUMMARY OF TESTS USED
IN DETERMINATIVE SCHEME

Medium	Observation
Nutrient Agar (Marine)	Colony Appearance Gram Stain Morphology Oxidase Test
Nutrient Broth (Marine)	Motility Morphology
Hugh and Liefson's Medium	Dissimilation of Carbohydrates
Nutrient Agar Slope	Flagella Stain



Determinative groupings

TABLE 10. OCEANOGRAPHIC AND CHEMICAL DATA
FOR THE ITB EXPOSURE — ATLANTIC OCEAN
AREA (JUNE 10, 1974)

Ocean	Dock
Conductivity — 52.3 millimhos/cm	Conductivity — 45.0 millimhos/cm
Salinity — 33.9 ppt	Salinity — 28.0 ppt
Temperature — 26.2°C	Temperature — 28°C
pH — 8.2	pH —
DO — 4.6 ml/l	DO — 4.4 ml/l
Turbidity — 1.22 m (Visibility)	Turbidity — 0.762 m (Visibility)



Figure 52. ITB anchored offshore in the Atlantic Ocean.

were placed between the angle iron and the connecting bolts and screws to prevent a galvanic field conducive to corrosion. The bolts and screws were also protected by primer paint. The two angle iron fixtures were mounted inside the ITB at angles to each other as shown in Figure 53.

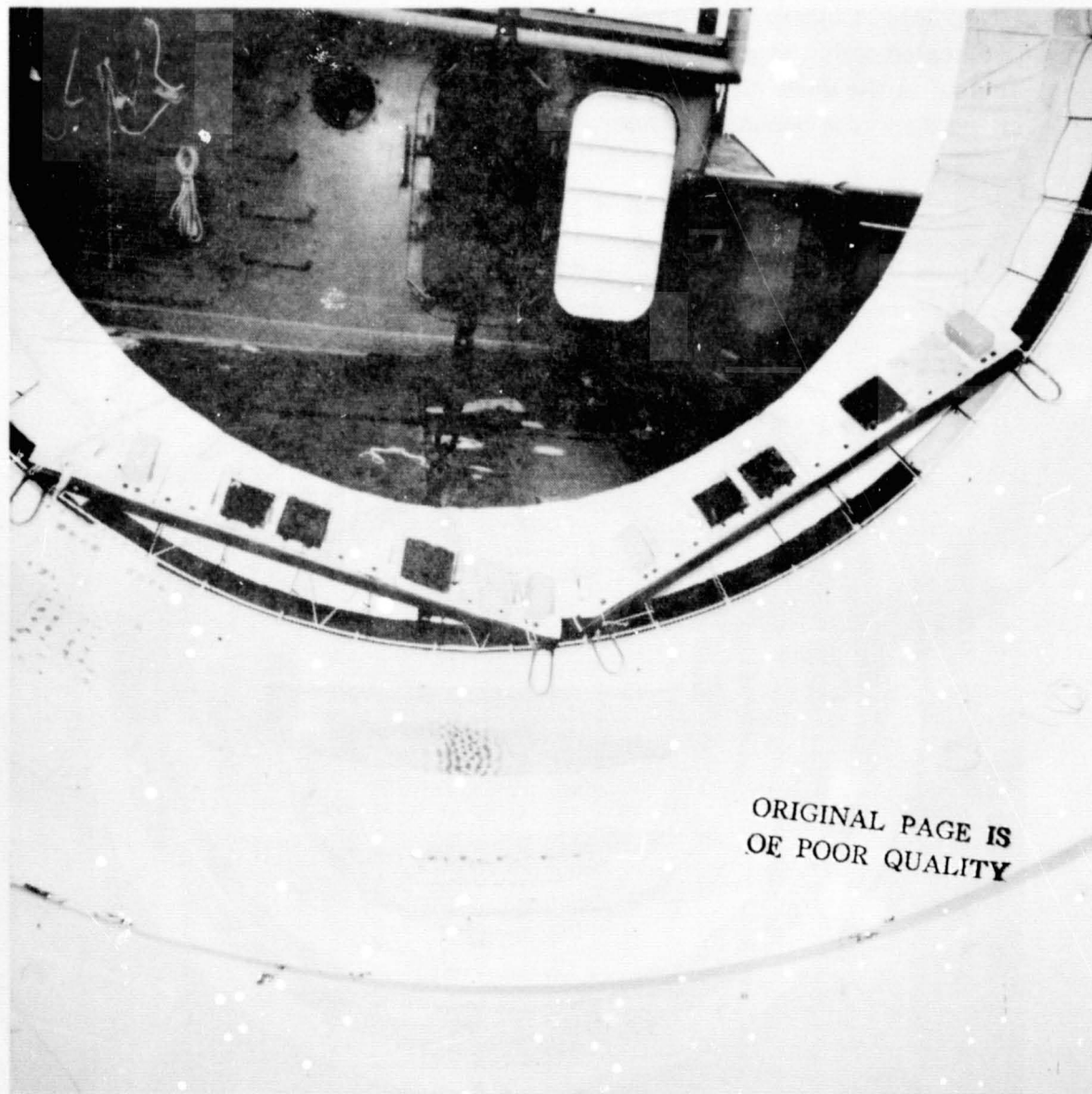


Figure 53. ITB showing panel racks.

At recovery, June 9, 1976, the ITB was brought aboard and placed in a horizontal position for convenience of culturing (Fig. 54). After sampling was completed, the ITB was lowered into the ocean 3.218 km (2 miles) from this site and towed at 2 knots/h. It was positioned 121.72 m (400 ft) behind the ship on the starboard side of the LCU recovery vessel (Fig. 55). After 1 h of towing, the ITB was brought aboard by the ship's crane and set in a vertical position (Fig. 56). Cultures were taken of the outside, and a sprinkler system of perforated teflon was placed around the top outer edge to keep it wetted until arrival at the dock site (Fig. 57). The ITB was placed in the Banana River at the dock site opposite Hangar AF for 24 h (Fig. 58).

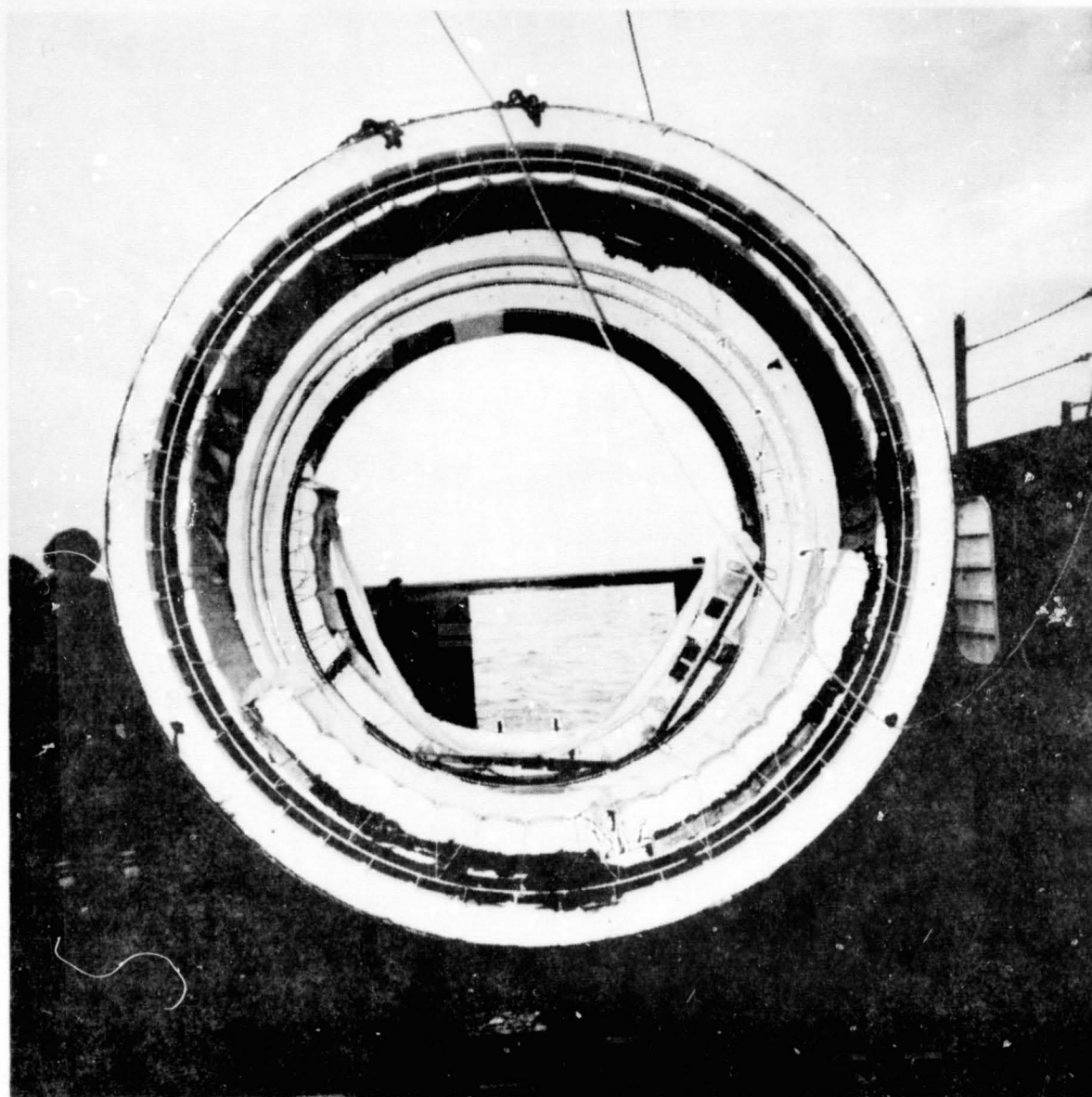


Figure 54. ITB aboard ship after recovery.



Figure 55. ITB under tow.

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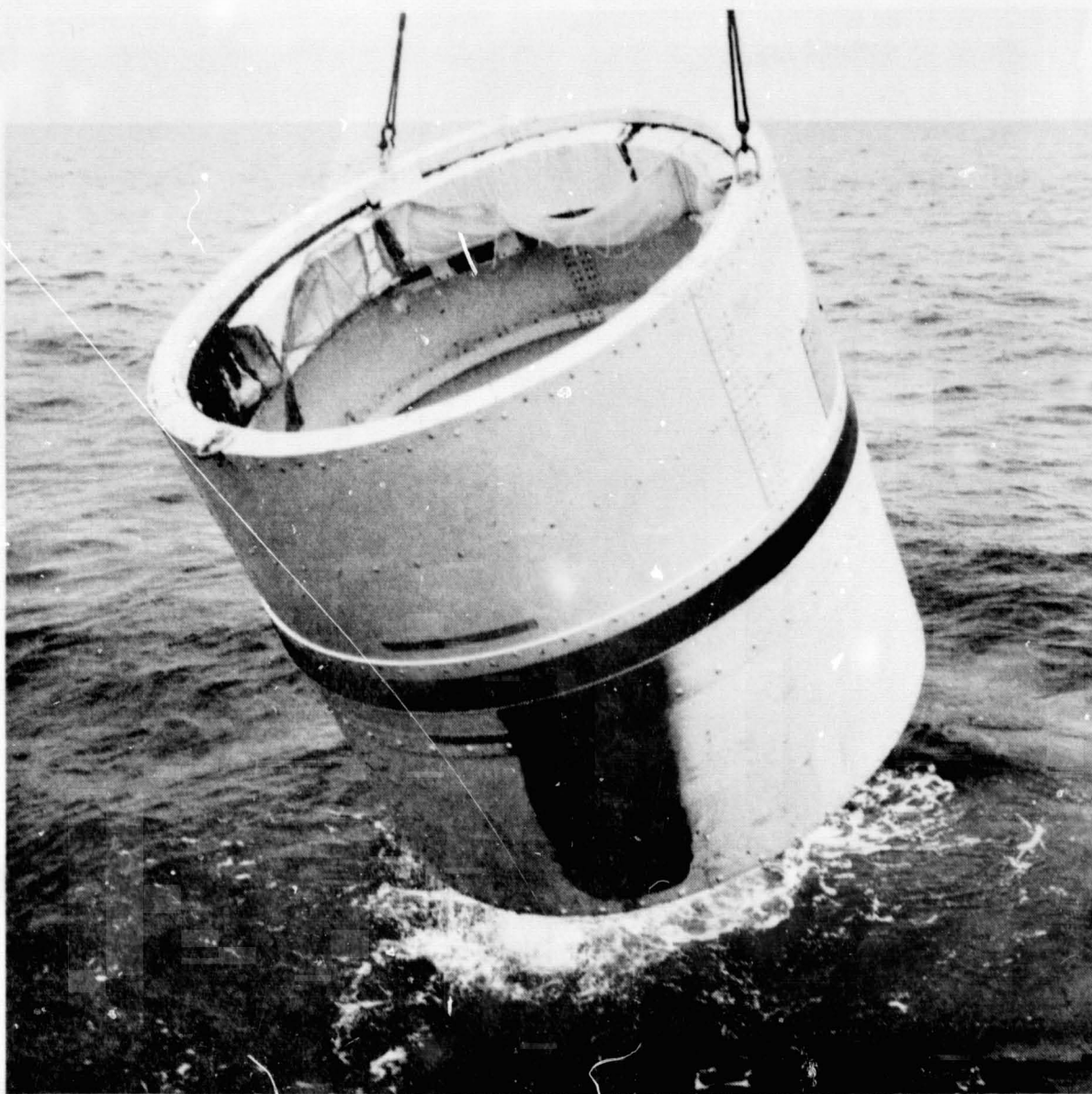


Figure 56. ITB after tow showing interior condition.

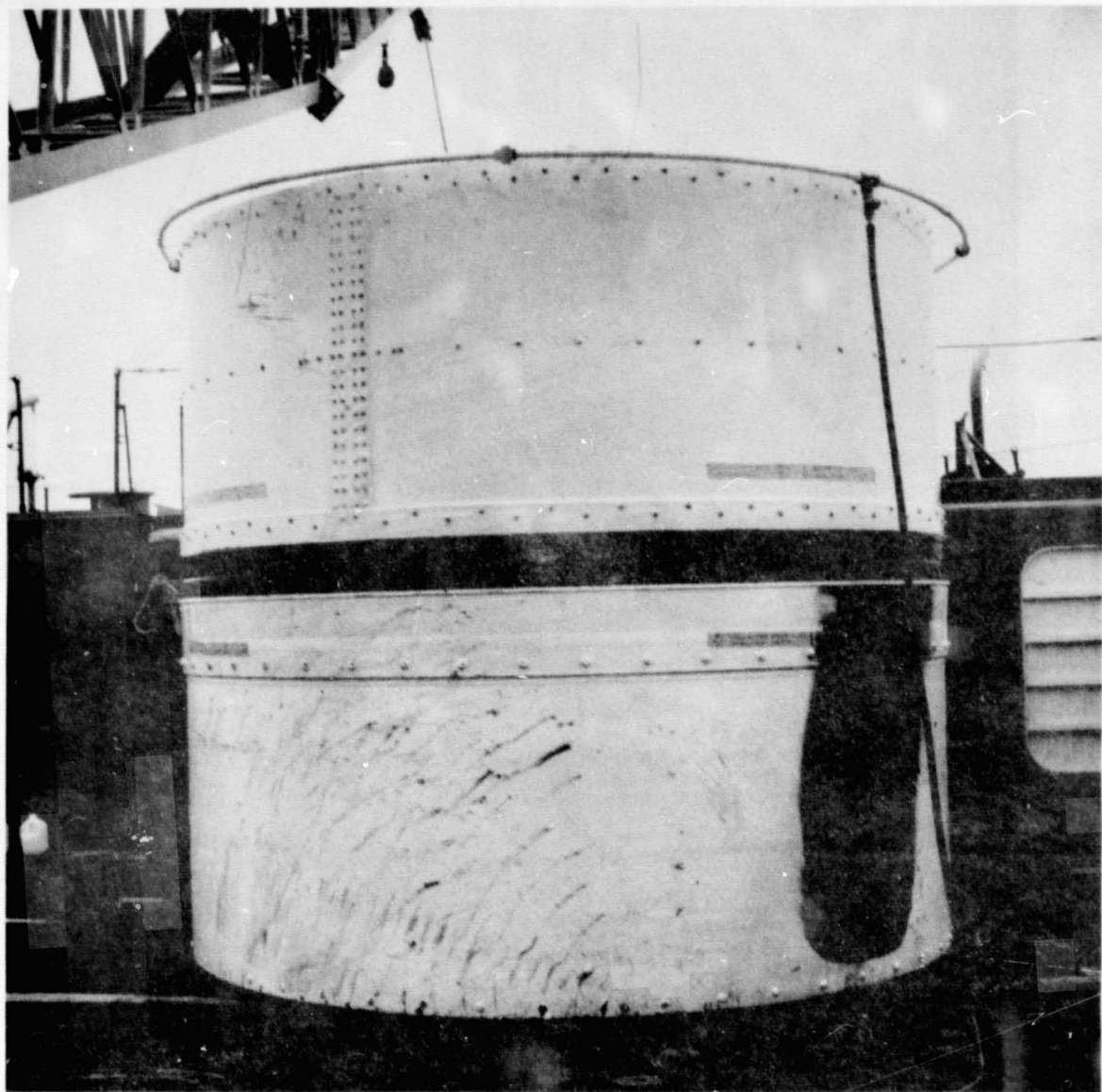


Figure 57. ITB aboard ship with sprinkler system installed.

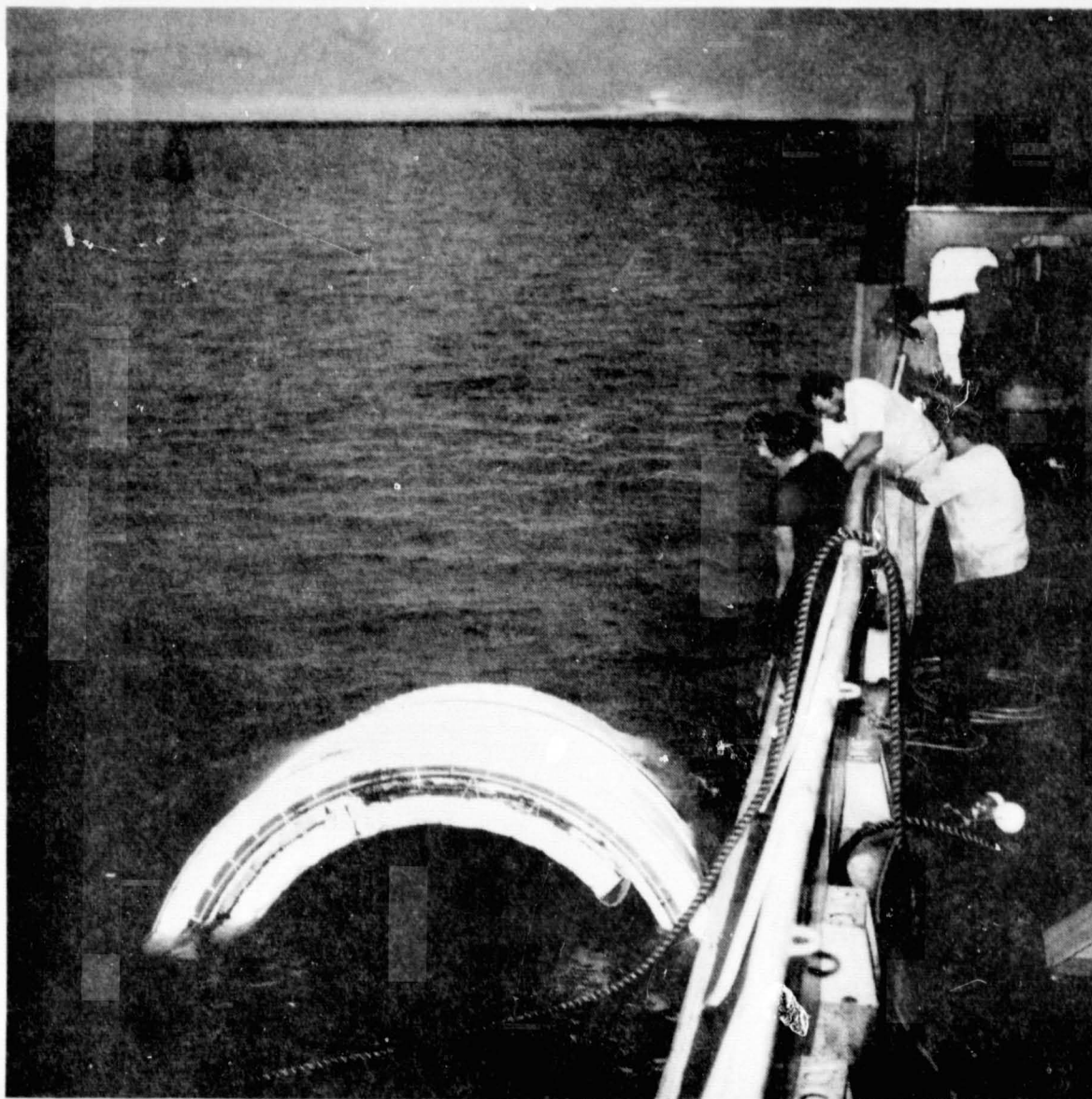


Figure 58. ITB dock site testing.

After 3 days, the ITB was hoisted onto the NASA barge. Photographs were made and cultures were taken. The ITB was then shrouded and returned by flatbed truck to MSFC.

E. Basket and Rack Test Program Using Small Scale Samples (July 1977)

1. Discussion. As a result of earlier test programs on small scale samples and the ITB, it was considered necessary to further substantiate and verify previous SRB materials selection. These summer of 1977 tests were performed in the ocean environment as were previous tests, but were limited to small scale samples that could be mounted to a basket or rack. These samples and/or components are as follows:

- a. Electrical subsystem — Black box with extra noncoated plates
- b. MSA-1 — Test panels
- c. Flotation panel
- d. 18 in. Cylinder — Clevis joint seal (Thiokol)
- e. D6AC test panels w/ zinc rich primer and topcoat (epoxy),
D6AC test panels w/ red lead primer and topcoat (epoxy)
- f. Sealant/bolt samples using approved sealant PR 1422, DC 93-076,
and a new untried sealant PR 1436
- g. TVC Components — One each fluid manifold assembly and one
each auxiliary power unit
- h. Parachute material samples
- i. Test panels with "B" stage cork
- j. Biological samples consisting of: coated 7075 aluminum, coated
2219 aluminum, coated D6AC steel, and various test buttons on an assortment
of materials.

Tables 11 and 12 present the environmental conditions under which the test was made.

TABLE 11. SRB TESTING SITE DATA (JULY 1977)

Testing Sites:

Oceanic — Atlantic Ocean, approximately 640 m (700 yd) off-shore; position 28°36'08"N, 80°34'47"W in 4.57 m (25 ft) of water.

Dock — Banana River, adjacent to Hangar AF, approximately 91 m (100 yd) from shore in 9.1 m (30 ft) of water.

Exposure Time:

Oceanic Site — 7 days

Dock Site — 24 h

Test Vehicles:

1. Thiokol cylinder, nylon parachute strips, SEM buttons, test basket
2. Flotation panels
3. Test rack

Test Protocol:^a

1. Thiokol Cylinder — Submerged
2. Flotation Panels — One end submerged
3. Test Rack — Splash level

- a. Test vehicles transported aboard ship from ocean site to Pt. Canaveral. Kept wetted by sprinkler system of ocean water. Transported by truck from Pt. Canaveral to dock site.

TABLE 12. HYDROGRAPHIC AND MICROBIOLOGICAL DATA
FROM ATLANTIC OCEAN AND BANANA RIVER
FOR SRB TESTING (JULY 1977)

Measurement	Atlantic Ocean	Banana River
Salinity (ppt)	35.0	32.5
Temperature (°C)	25.0	30.0
Dissolved Oxygen (ppm)	5.8	5.2
pH	8.2	8.1
Mean Number of Bacteria/ml	17.0	165.0
Mean Number of Antibiotic Resistant Microorganisms/ml	0.0	10.0

Note: SEM stub area — 0.19 in.²
Rodac plate area — 4.9 in.²

The Test Sample Basket and Rack were anchored in the Atlantic Ocean Test Site off KSC on July 13, 1977, for a 7 day exposure. Samples representative of materials specified in the SRB were prepared for corrosion and biogradation testing. Those samples requiring test in the splash zone were mounted in the basket (Figs. 59 and 60) for the flotation system. Teflon washers were placed between the samples and mounting frames to prevent a galvanic field conducive to corrosion. Those samples requiring submersion [18 in. D6AC Clevis Joint Sample (Thiokol) with the factory applied EPDM rubber seal vulcanized in place; nylon curtain material samples; and biological test buttons] were mounted to the specially designed rack (Figs. 61 and 62).

At recovery on July 20, 1977, the basket and racks were brought aboard ship and placed in such a manner that the sprinkling system could be mounted and all samples remain wet on return to port. Prior to the mounting of the spray system, the nylon curtain strips were removed from the rack, placed in an

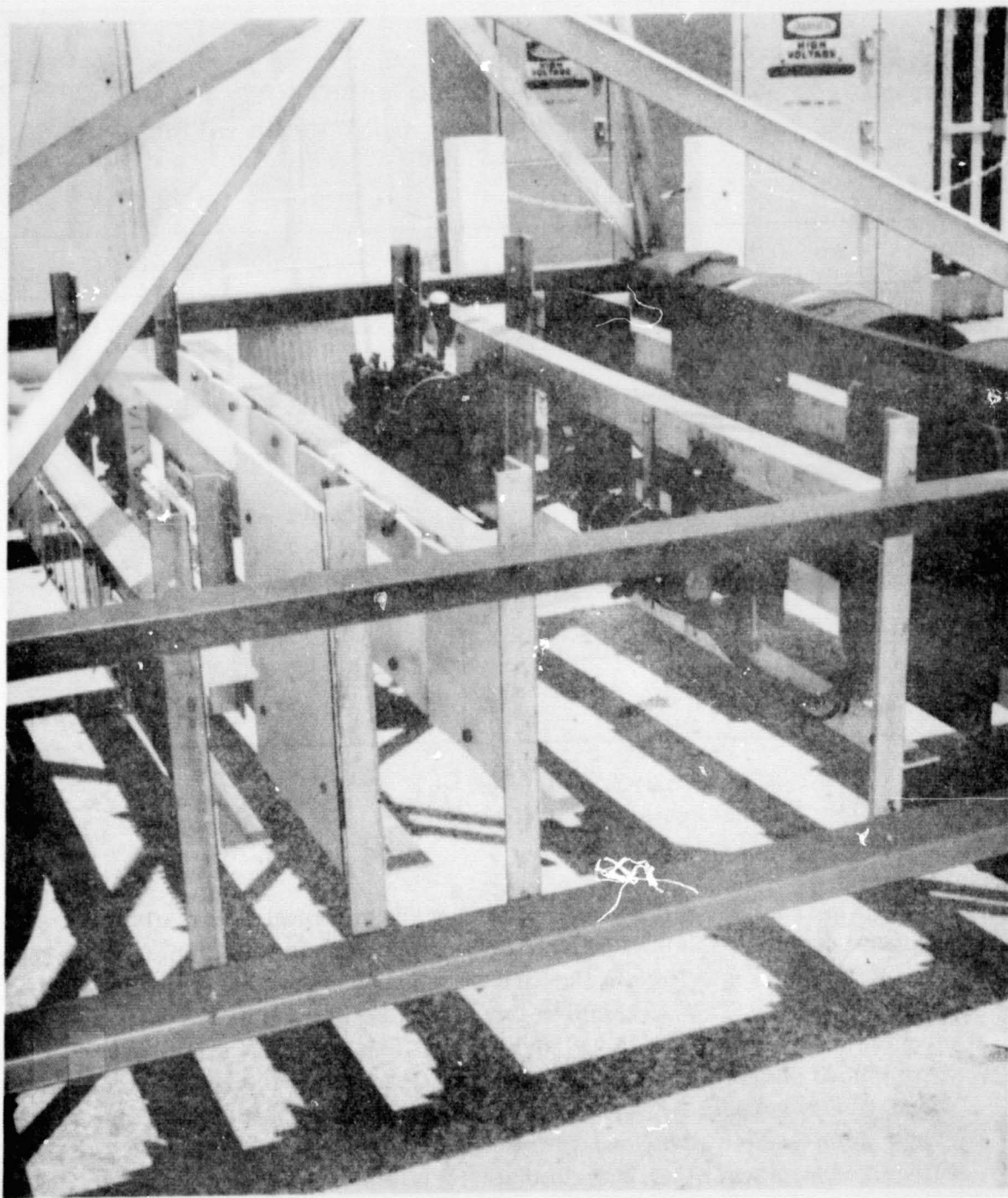


Figure 59. Test rack.

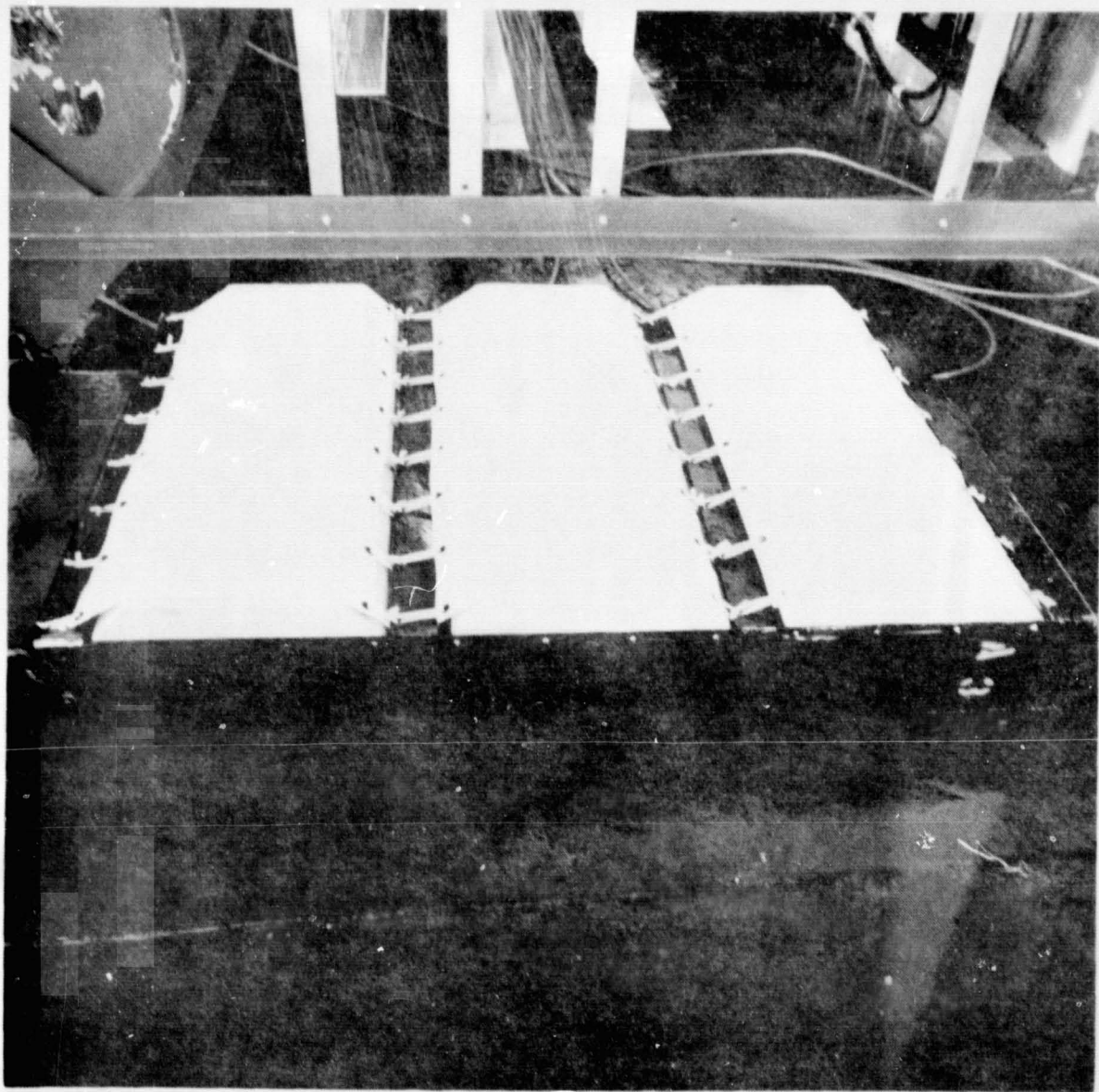


Figure 60. Flotation system.

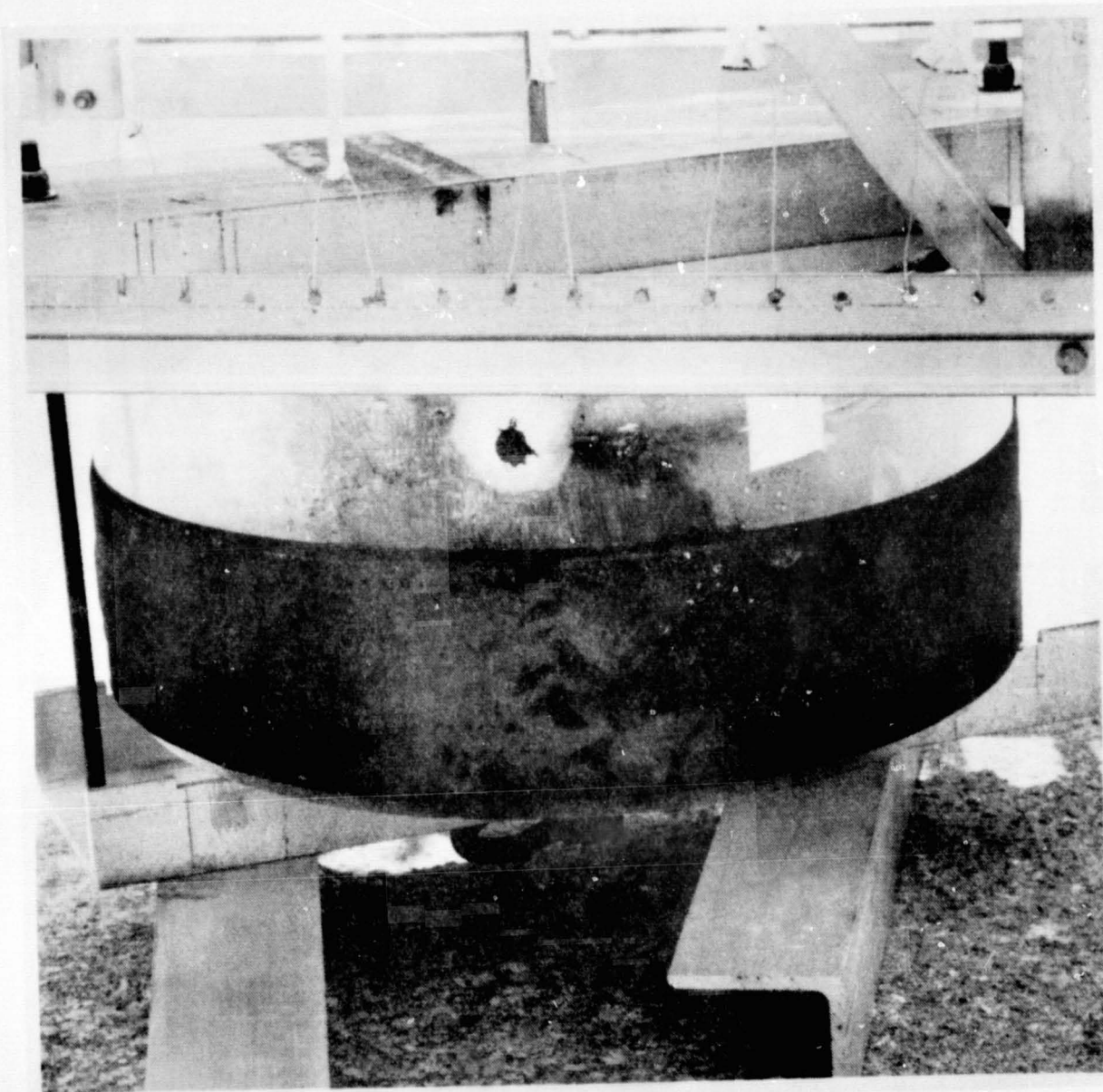


Figure 61. EPDM vulcanized rubber 18 in. test cylinder (Thiokol).



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Figure 62. Nylon parachute material specimens.

opaque container, partially filled with ocean water, and sealed. Biological specimens (smears-cultures) were taken from each test article and were supported by photographs delineating conditions. The sprinkler system (ocean water) was then activated (Fig. 63).



Figure 63. Test rack sprinkler system.

The basket and racks and all candidate test specimens were then placed in the Banana River Test Site for 24 h with the exception of the nylon parachute test specimens which had previously been packaged aboard ship. At the conclusion of the 24 h dock site test, the basket and racks were removed from the water and placed on dock where visual examination, biological sampling, and photographing were accomplished. All samples were then loaded on a flat bed truck, transported to the O&C Bldg., KSC, unloaded, and allowed to remain on the baskets and racks overnight. All samples were then removed and rephotographed. All items were then packed and returned to MSFC for further evaluation.

2. Parachute Strips and SEM Stubs Covered with Parachute Materials.

The parachute strips (Table 5) were approximately 6 ft long and were suspended vertically on the test vehicle. This test article, therefore, was immersed 0 to 6 ft. The scanning electron microscope (SEM) stubs were fastened to TVC tubing and secured to the parachute structure at mid-point, giving the stubs a 3 ft immersion.

The parachute strips and the SEM stubs covered with parachute material were tested in the ocean area only, because the parachute will be recovered from the ocean immediately upon splash down. After 7 days ocean exposure, the strips were removed from the test vehicle and returned in a container of seawater to MSFC for further assay and tensile strength testing.

In addition to the strips, SEM stubs were covered with types of parachute material and mounted in the test vehicle (Fig. 9). Upon recovery from ocean exposure, these stubs were immediately fixed in gluteraldehyde for SEM analysis by the University of Maryland, and duplicate samples were streaked onto 2216 marine agar plates for taxonomy assay. Duplicate parachute samples were placed in vials (unfixed) for transport to the University of Maryland.

F. KSC Test Rack Biological Test Results **(January 12-30, 1976)**

Microbial laboratory testing revealed gram negative organisms from the salt and brackish waters at the test sites. *Pseudomonas*, *flavobacter*, *vibrio*, and *achromobacter* organisms were most prevalent in these waters. Slime mold, tunicates, hydroids, and barnacles were visible on the panels.

There was no apparent degradation to the undamaged coatings on the topcoated surfaces (Figs. 64 and 65), but abrasion and chipping produced habitats for quantities of marine growth, particularly on the 7075 aluminum where a visible growth of slime mold, tunicates, hydroids, etc. existed (Figs. 66 and 67). It was noted on all panels that a film developed and organisms were attached during each phase of testing. The fasteners were very susceptible to physical damage, i.e., loss of coatings. However, the fastener material (286 stainless steel) is evidently not a good nutrient for marine organism growth as photographs show no evidence of organism accumulation. The timed photographs of 72 to 332 h for panels in dock water show a progression of growth on the 7075 aluminum. This would cause concern if this material were used on the SRB without the assurance of a permanent coating. If damage should occur to the coating, microbial growth could spread under the coating and cause damage even while the vehicle is in storage. This situation can produce an environment conducive for growth of other terrestrial organisms. Photographs of the test panel rack reveal the microbial buildup on uncoated panels at splash level and the effect of cleaning on these panels (Figs. 68 and 69).

G. ITB Biodegradation Test Results

Rodac plates with marine agar were used to culture most of the ITB with swab culturing used as an alternate. The small rodac plate contains media which extend above the plate rim. These media are touched lightly to the surface area to capture the microorganisms. This method is much faster than the swab technique.

In the laboratory, pure cultures were isolated onto new appropriate marine media. The Shewan Scheme of differentiation was again used for microbial general identification. It was found from the water samples that the microbial population had more than doubled in both the ocean and dock site since the last exposure testing (January 1976). This is normal, as some marine organisms double their populations with each 10 degree rise in temperature. The same general types of organisms were found: achromobacter, flavobacterium, pseudomonas, vibris, and seromonas. Panel 4 (MSA-1 coated with Hypalon — uncharred) carried the greatest mixed cultures with all of the previously mentioned organisms present. This indicates that panel 4 is a good general nutrient. Photos of rodac plates of ocean test cultures are shown in Figure 70. It was also noted on arrival at MSFC that panel 4 had bleached a lemon color in its container of seawater. In addition to microbial growth, the ITB was found to have attracted shrimp, barnacles, slime mold, fungi, and algae during this exposure test. Some photos of damages and accumulations are shown in Figures 71 through 74.

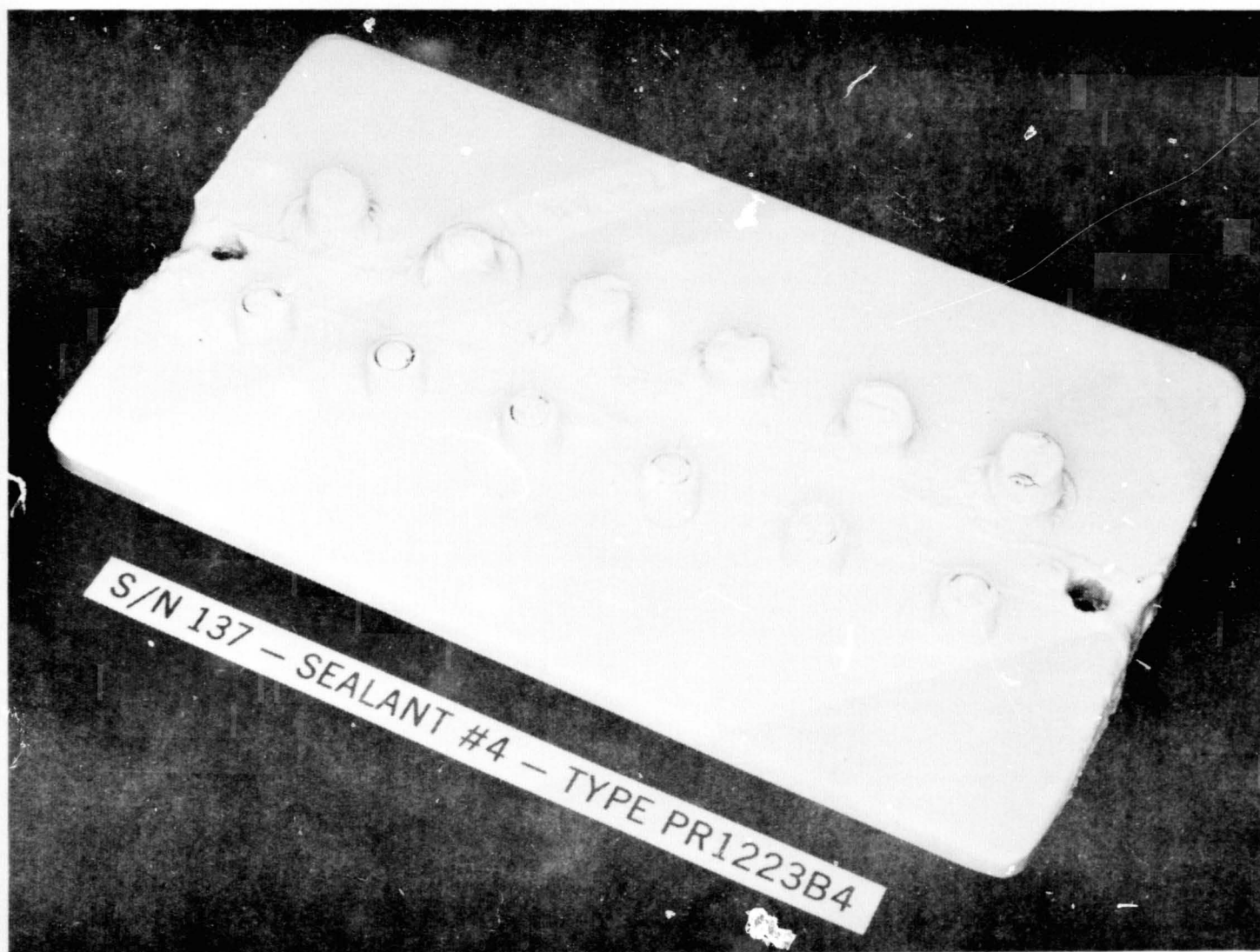


Figure 64. Panel No. 137 before testing.

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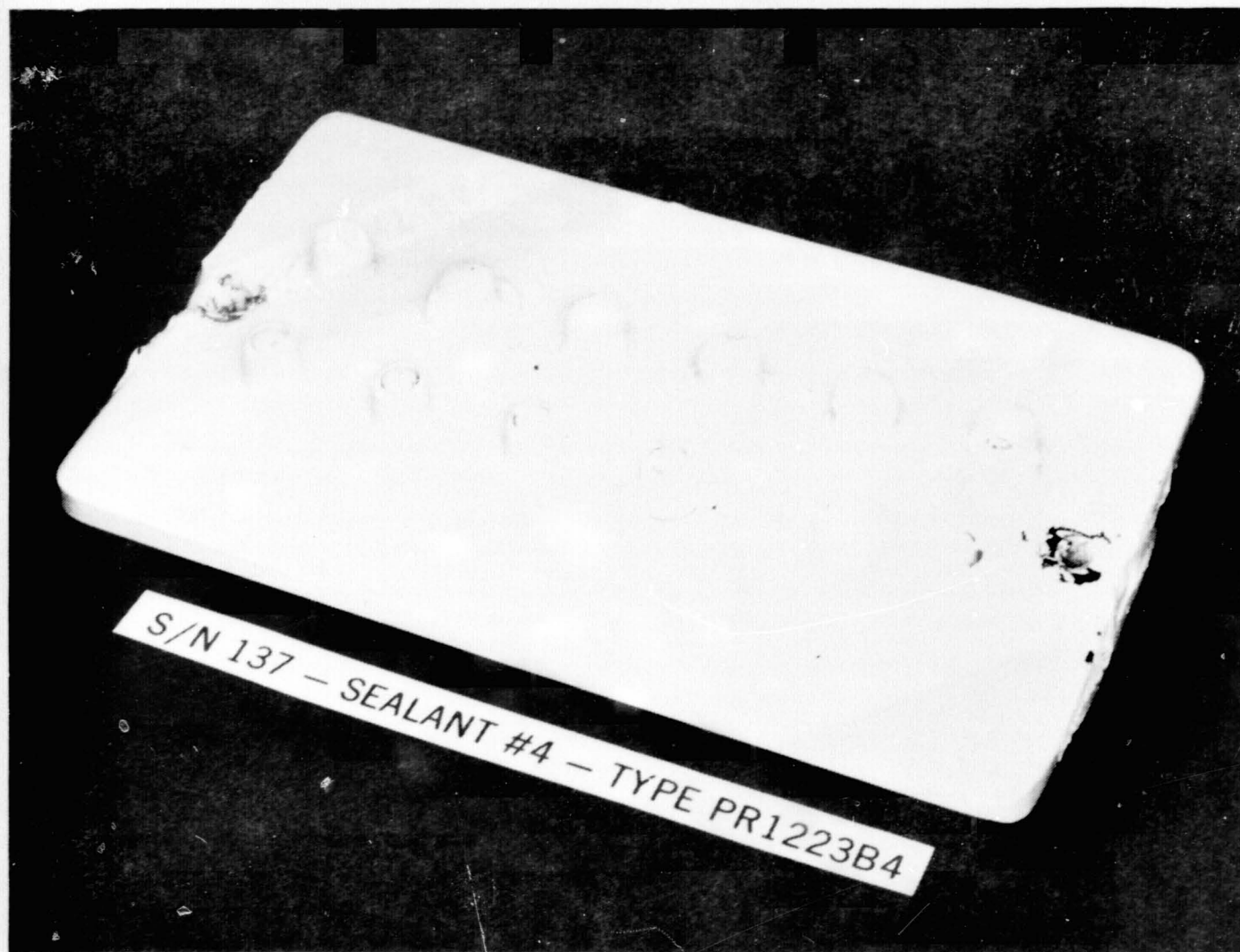


Figure 65. Panel No. 137 after testing and returned to MSFC dry.

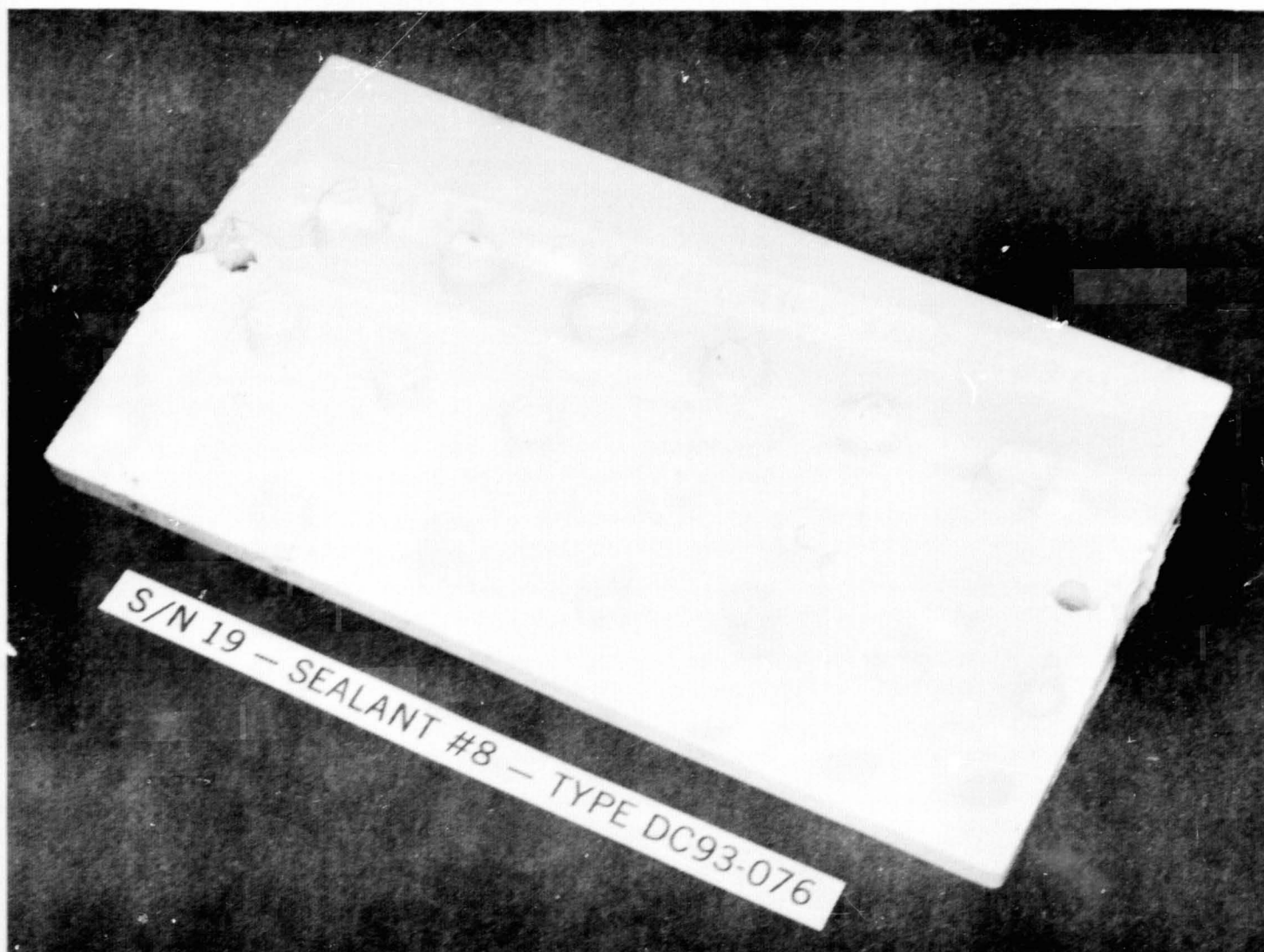


Figure 66. Panel No. 19 before testing.

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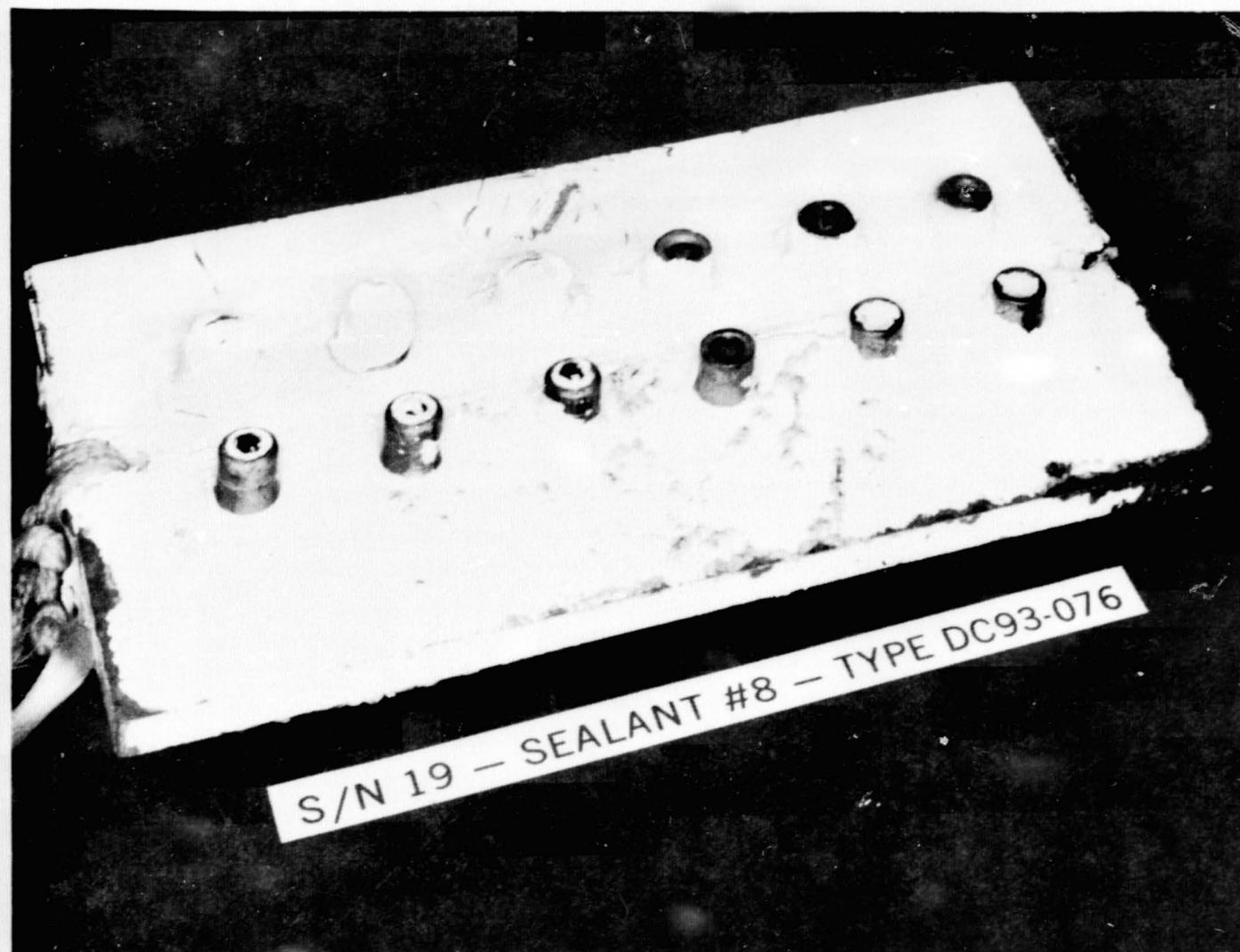


Figure 67. Panel No. 19 after testing and returned to MSFC wet. (This panel was suspended from test rack to a depth of 3 ft.)

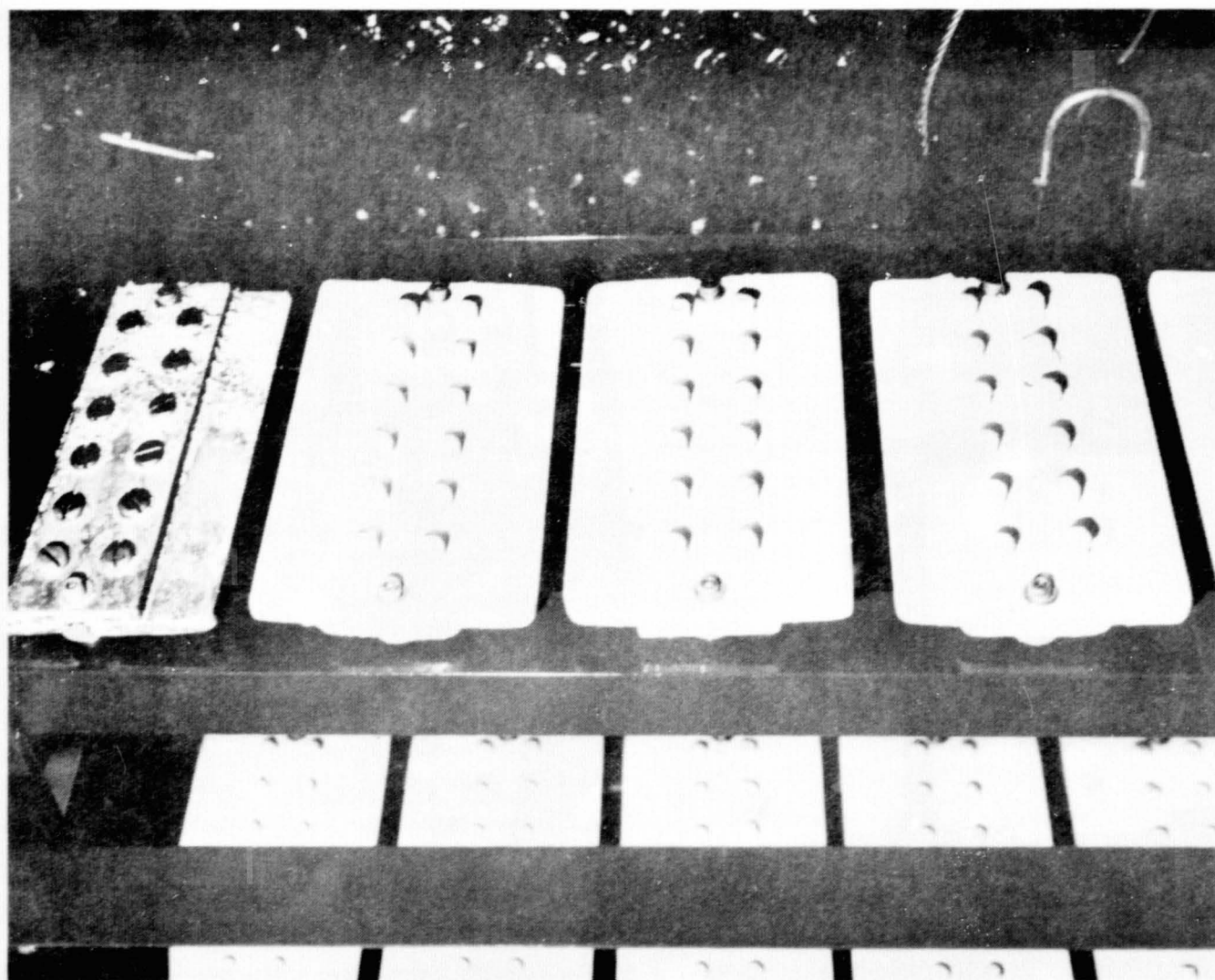


Figure 68. The test rack aboard tug after the first 5 day exposure to the sea.
(Right side of rack — panel Nos. 137, 190, 126, and 183.)

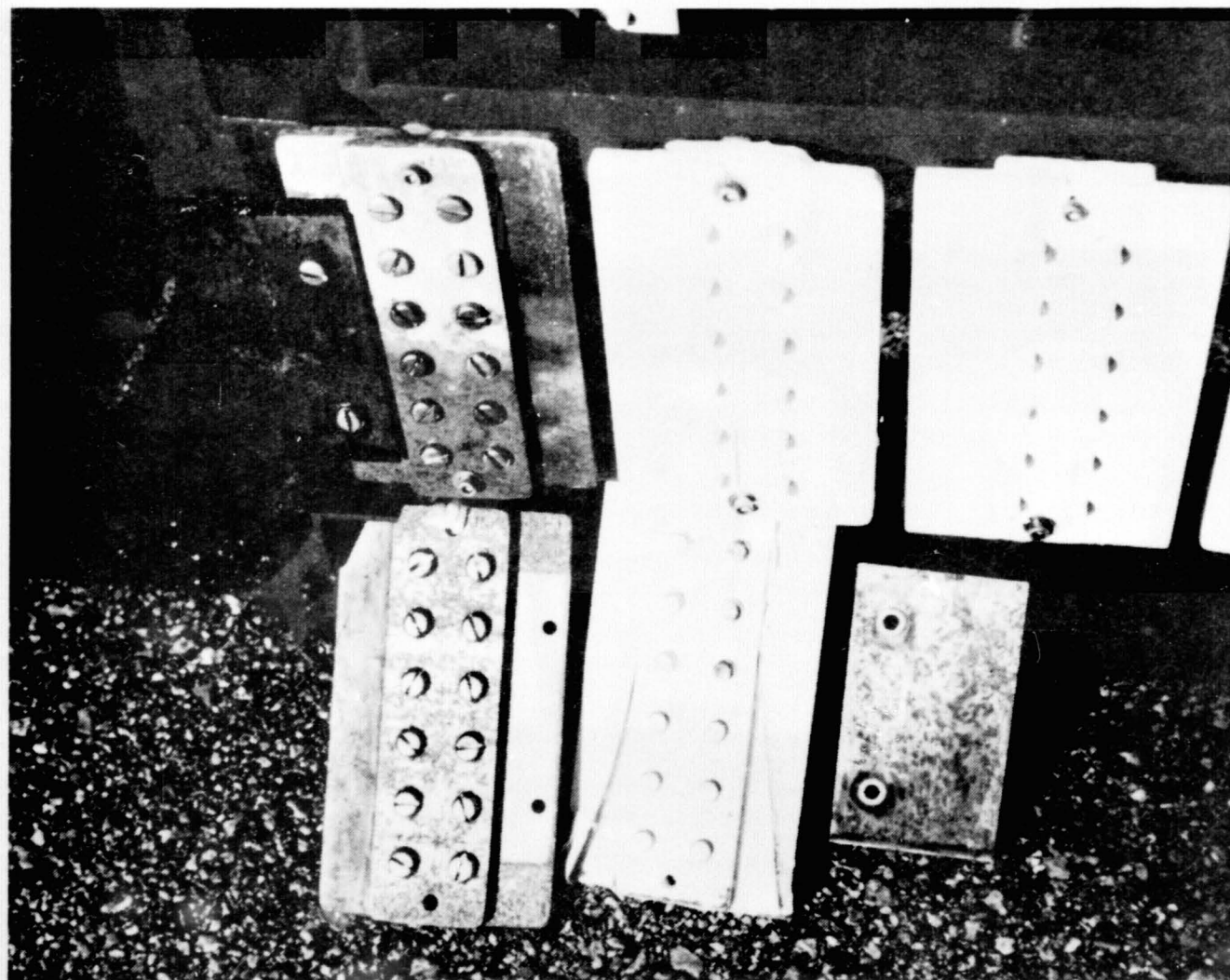


Figure 69. Sample panels after cleaning.



Figure 70. Rodac plates of ocean test cultures.

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Figure 70. (Continued).



Figure 70. (Continued).

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Figure 70. (Continued).



Figure 70. (Concluded).

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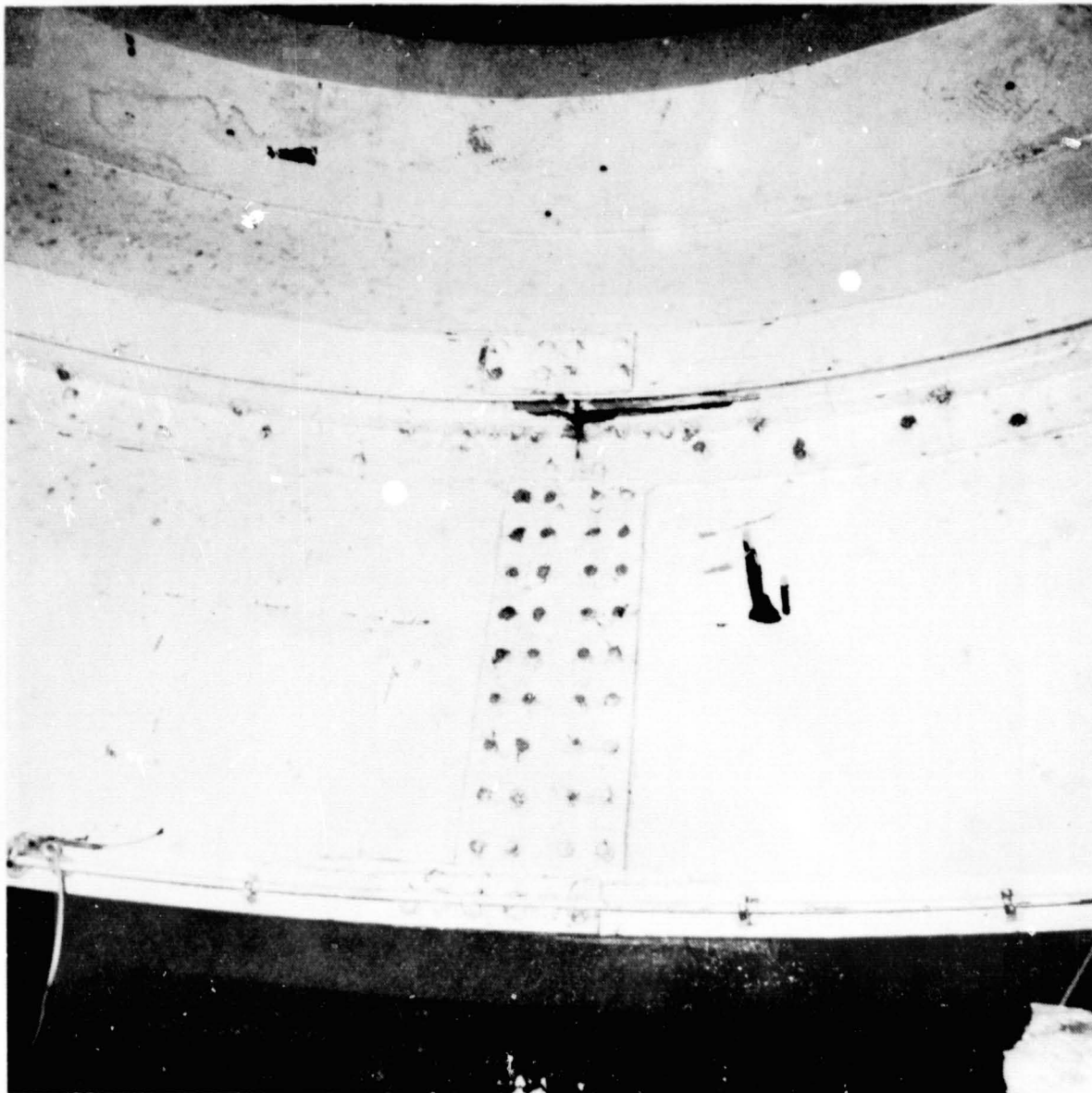


Figure 71. Biodegradation of structure.

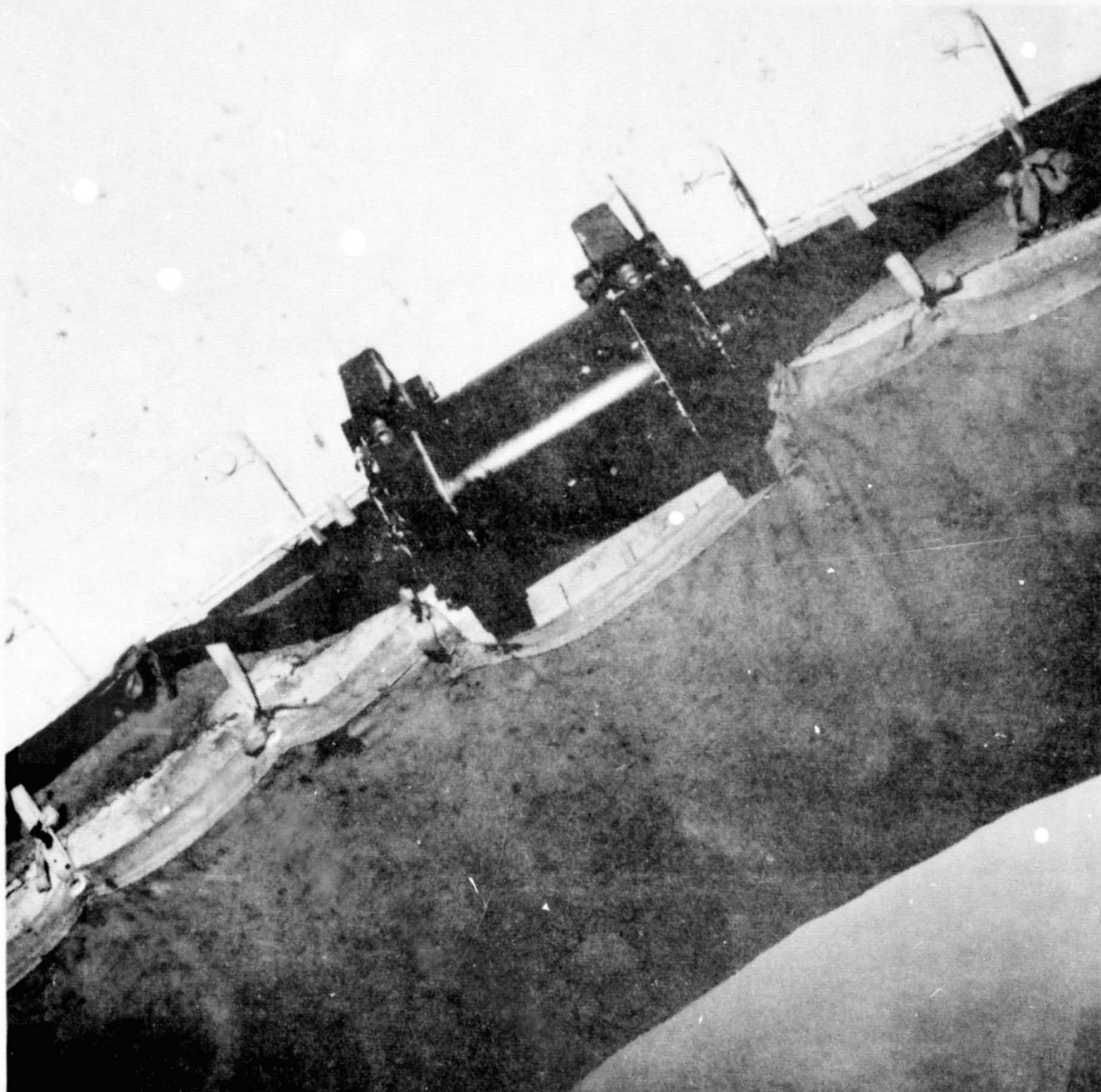


Figure 71. (Continued).

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Figure 71. (Concluded).



Figure 72. Typical accumulation of barnacles on buoy
after 5 months exposure.



Figure 73. Removal of barnacles from buoy.



Figure 74. Barnacles on buoy chain.

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H. Basket and Rack Biological Test Results (July 1977)

Upon recovery from the ocean, the test articles appeared very clean and in good physical condition due in part to the excellent weather conditions during the test period (Figs. 75 through 78).

Immediately upon recovery from each test site and after rinse or hose-down at the dock site, assay was performed by rodac touch plates for quantitative colony counts. The Schwamm scheme for determinative microbial groupings was used and the data agreed with the previous findings consisting mainly of vibrio, pseudomonas, moraxella, and micrococcus. Although all material surfaces revealed microorganisms, the amount of fouling present differed according to the surface type. Also the effectiveness of cleaning differed with the surface type. On smooth surfaces, the tap water rinse by hose pressure was very effective as seen by photographs of the black box, coated D6AC, bearing, 2219 epoxy coated, cork bonding material, and coated 7075 material. However, the porous materials such as cork, burned cork, MSA, and burned MSA held the marine organisms and showed abundant microbial growth after rinse. The only way to determine if the material itself supports growth is in laboratory tests using bacteria and/or fungi.

Results also showed the silicone surface to be less susceptible to microbial colonization. The two types of polysulfide (1422G and 1436G) were judged to be equally susceptible to fouling, since both showed heavy deposition of bacteria, diatoms, and protozoan species. The MSA-1 TPS material revealed extensive patch fouling which was observed to comprise concentrations of bacteria, diatoms, and debris. The rough surface of the MSA-1 may act to trap these materials, but the MSA-1 was not as susceptible to uniform microbial colonization as was observed on other material surfaces as mentioned.

The SEM stubs were exposed to both seawater and dock site water with the exception of the ones surfaced with parachute material which experienced ocean exposure only. All SEM stubs were returned to the University of Maryland for further analysis. The stubs were made of 2219 aluminum and D6AC steel surfaced with the following SRB materials:

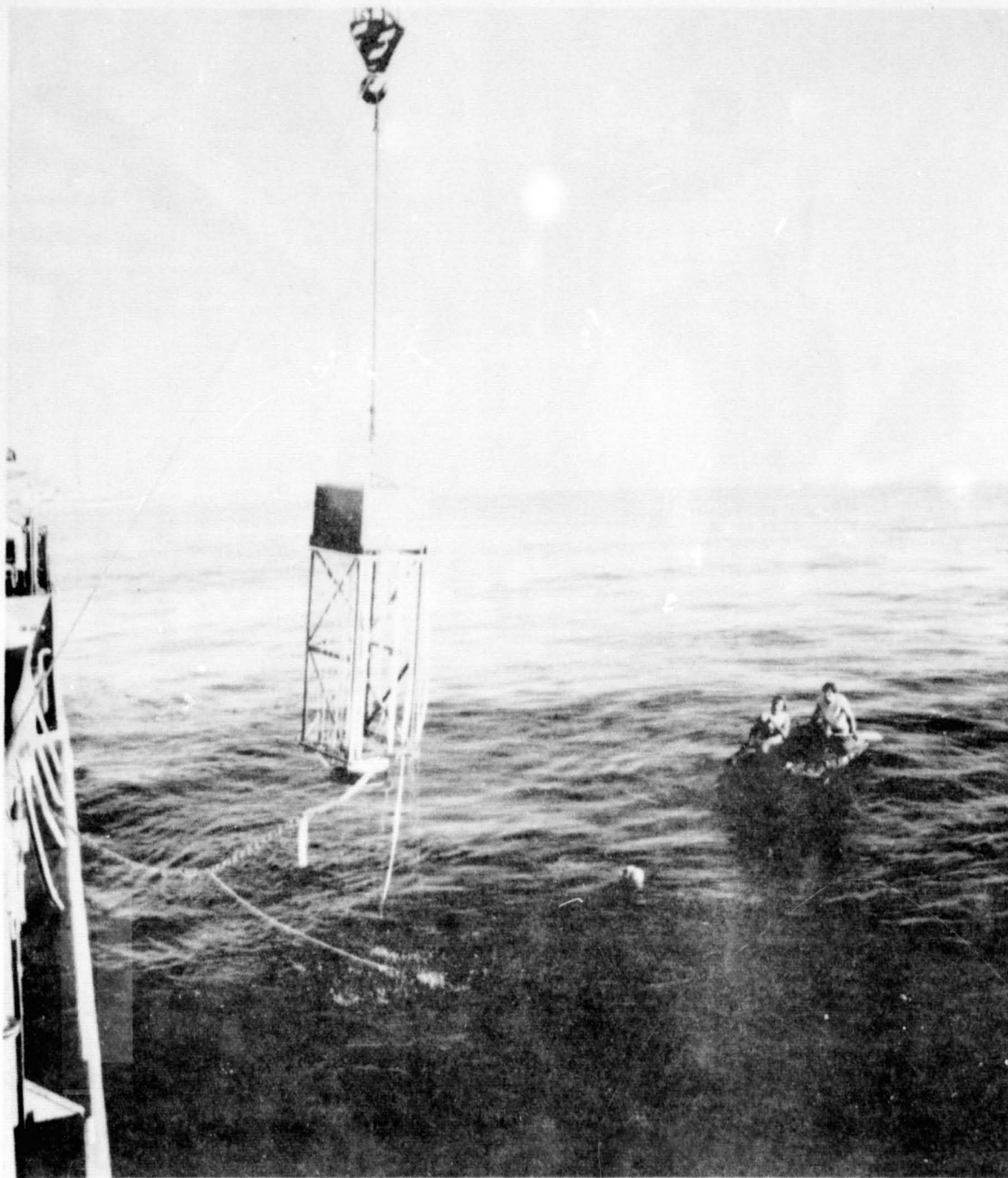


Figure 75. Nylon parachute strips and SEM buttons after 7 day ocean exposure.

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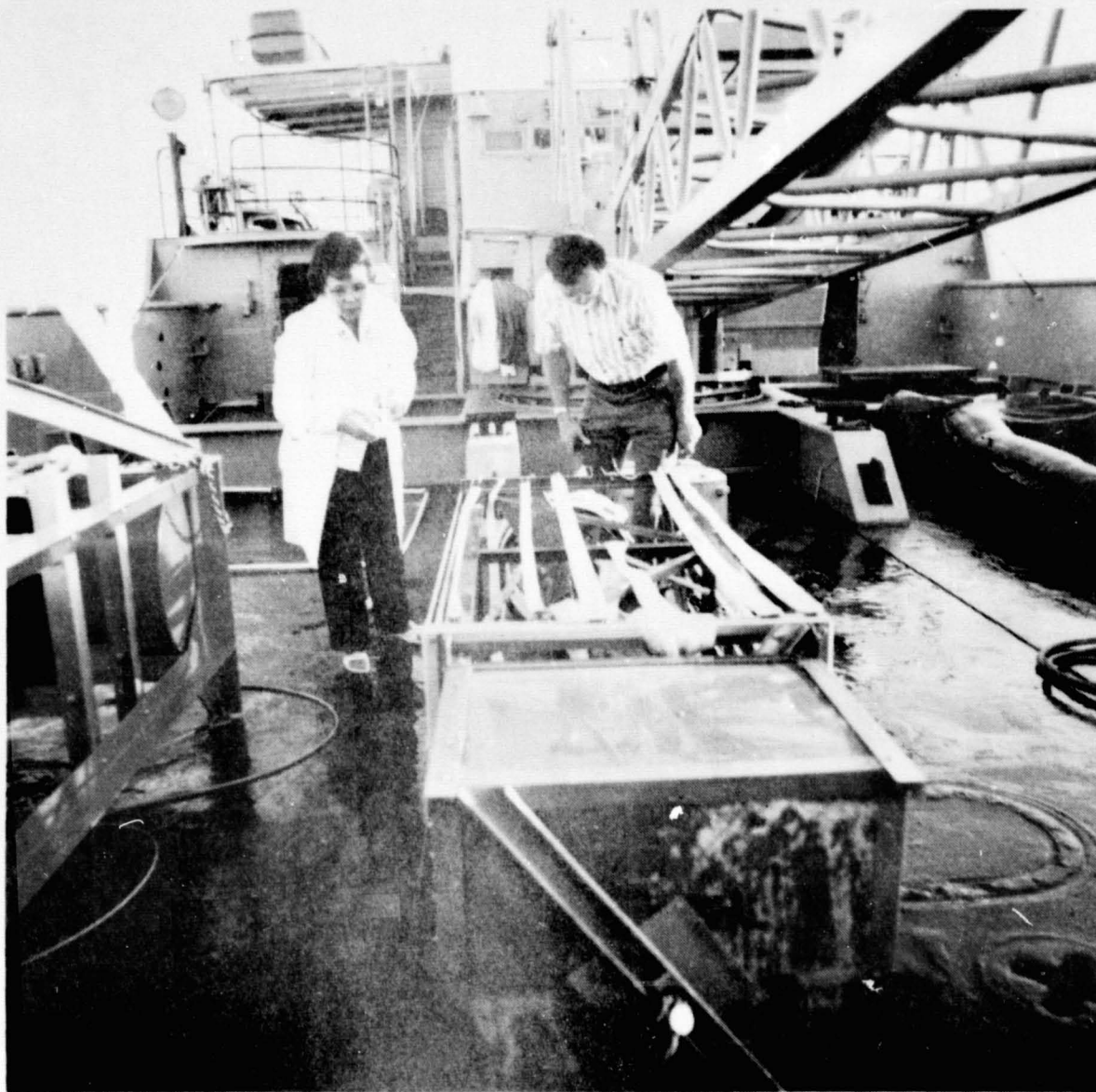


Figure 76. Removal of nylon strips and SEM buttons — completion of tests.

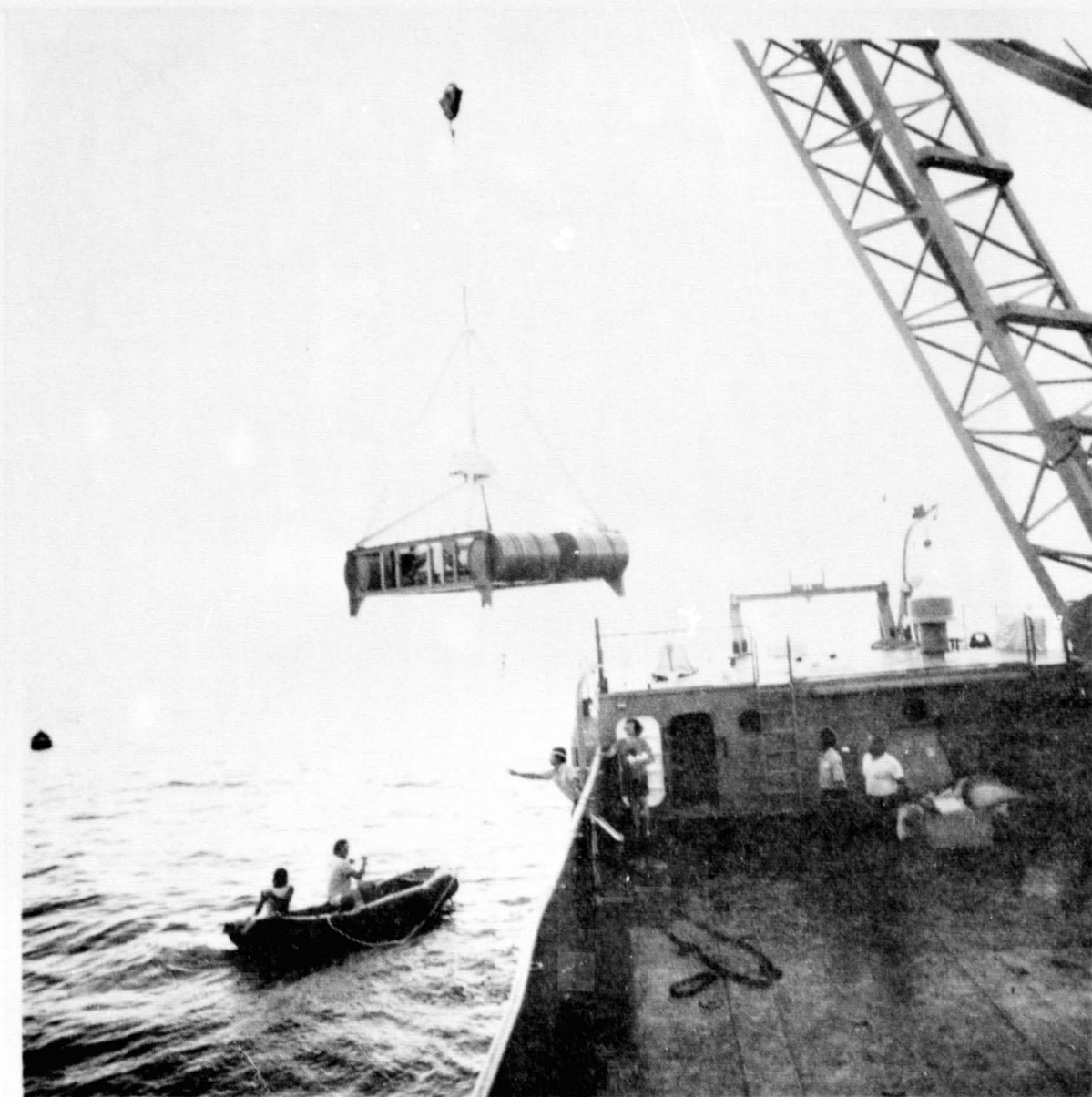


Figure 77. Retrieval of test rack from ocean test site.

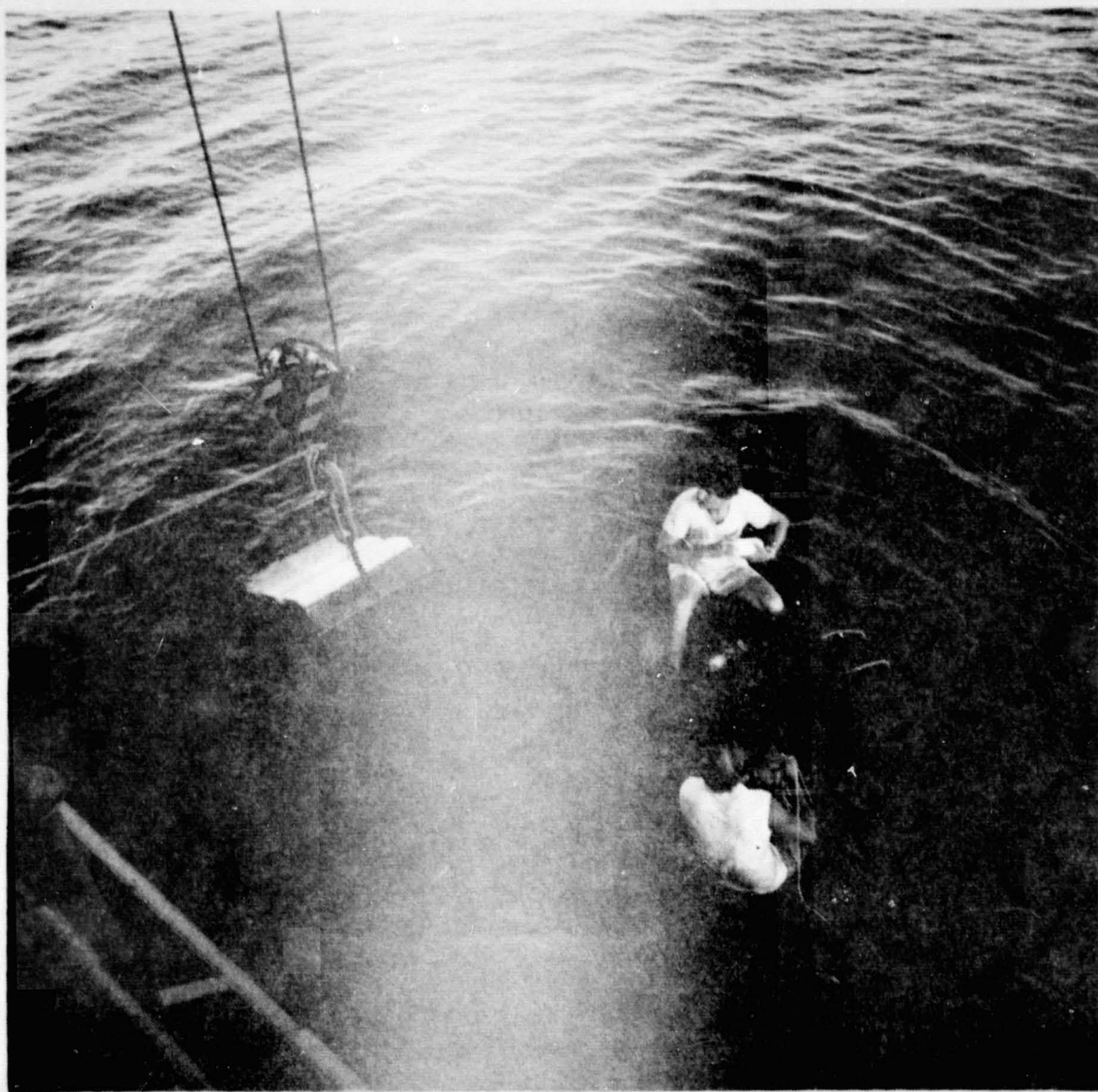


Figure 78. Retrieval of flotation system rack.

Red lead primer 9373 (Rustoleum)

Red lead primer 9373 + topcoat 9392 (D6AC) Rustoleum

Zinc seal primer 9334 (Rustoleum)

Bostik Finch 463-6-3 primer + topcoat 443-3-1 (2219)

Sealant PR 1436G (polysulfide, chromated)

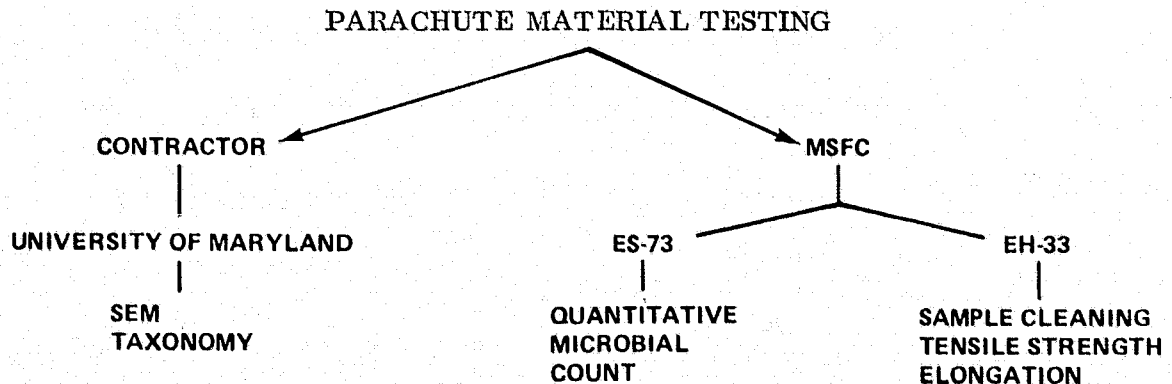
Sealant DC393-076 (Silicone, over DC1204 silane primer)

MSA-1 (TPS material)

Cork

Cork sealer.

After the final recovery from the dock water, the stubs were fixed in gluteraldehyde for SEM analysis, and duplicate samples were streaked onto 2216 marine agar petri plates. Surface water of the Banana River was also sampled by streaking stubs dipped in the water onto marine agar plates made up with and without antibiotics. The antibiotics in agar destroy bacteria and permit only the fungi to grow.



Figures 79 through 83 show the results from the SEM stubs. The contractor reports that after ocean exposure, the parachute material was found to be heavily coated with bacteria, diatoms, and debris. Also, a number of large hydroids were observed to be attached to the parachute material surface. The SEM samples returned to the University of Maryland were washed with distilled water, but remained heavily coated with organic material. Drying and distilled water washing destroyed the delicate biological structures of the hydroids and other microorganisms. Nevertheless, diatom shells could still be identified. The parachute material did not appear to be degraded during the process of microbial attachment as seen under the SEM.

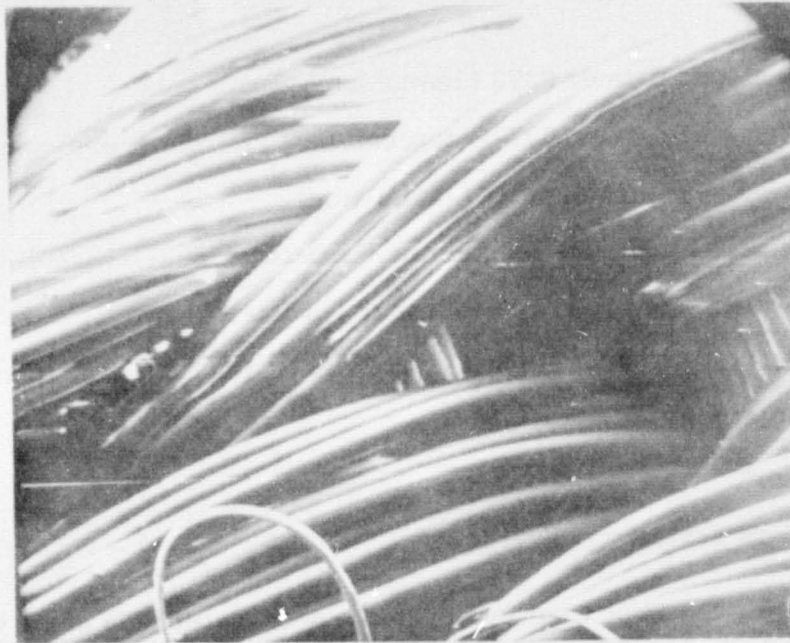


Figure 79. Parachute material (EH 33-3) prior to exposure to biofouling (the nylon strands are completely free of microorganisms) (125X).

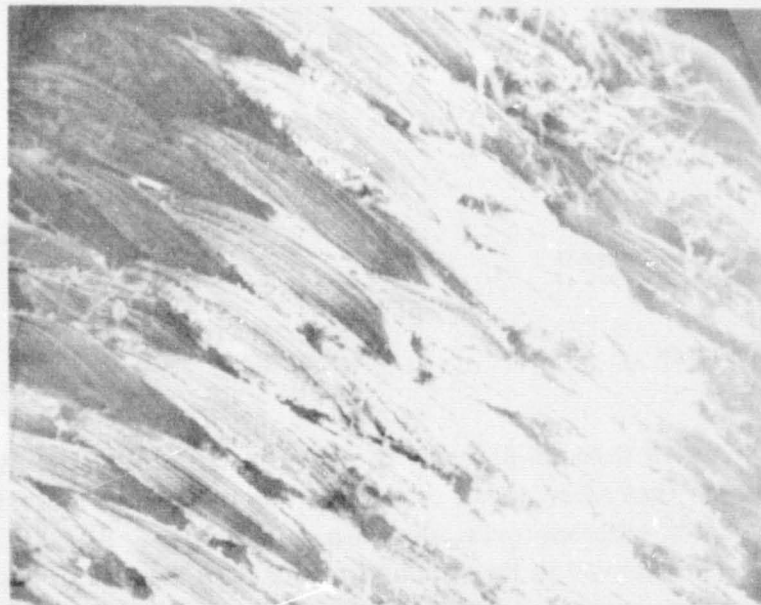


Figure 80. Parachute material (EH 33-3) after exposure for 7 days in the ocean [heavy surface fouling, including hydroids (upper right), is evident] (24X).

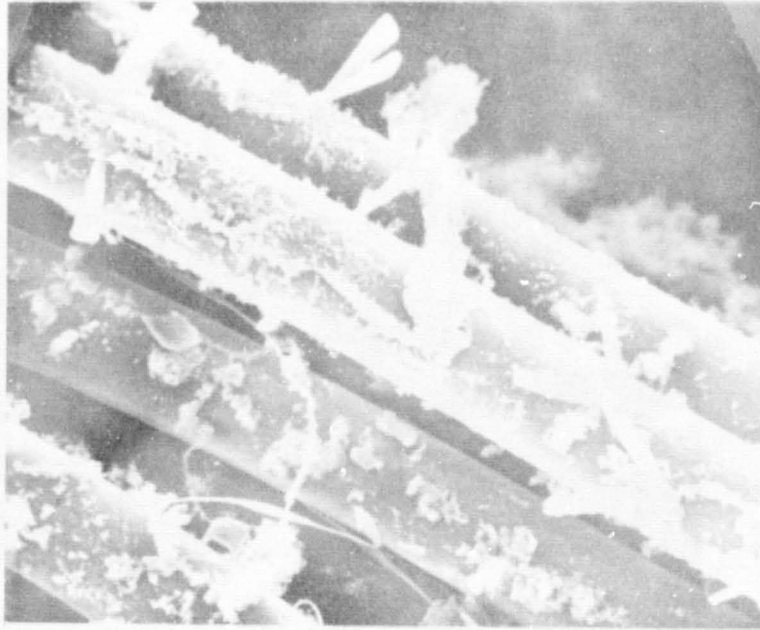


Figure 81. Diatoms and bacteria on surface of parachute material (EH 33-3) after exposure for 7 days to ocean water (590X).



Figure 82. Hydroids on parachute material (EH 33-3) after exposure for 7 days to ocean water (235X).

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Figure 83. Organic material remaining after distilled water wash of the surface of the parachute material (EH 33-3) exposed for 7 days in the ocean and stored 7 days prior to washing with distilled water (107X).

Quantitative microbial assay was accomplished by using rodac plates filled with 2216 marine agar and touching each plate directly onto the test material. This type test was performed:

- a. At ocean recovery
- b. At MSFC prior to cleaning
- c. After sample cleaning.

The parachute sample test was begun at the ocean site July 12, 1977. After seven days the samples were recovered and placed in a container of ocean water. On August 19 the samples were washed with tap water and dried in a 140°F oven. It is evident from the rodac plates that the organisms remained alive due to some nutrient. It is also evident that the tap water rinse did not remove the majority of these organisms. Some contamination was also seen after drying. The contractor reports the ocean organisms to be of the vibrio genera.

After the rinse and drying of the parachute samples, tensile strength testing was performed. Results and charts of elongation testing are shown in Table 13.

TABLE 13. COMPARATIVE BREAKING STRENGTH OR PARACHUTE WEBBING AND TAPE AFTER 7 DAY KSC SEAWATER SOAK, 3 WEATHEROMETER CYCLES AND UNEXPOSED MATERIAL

Sample Identification	KSC Seawater (lb)	Weatherometer (lb)	Unexposed (lb)
Mil W-83144, Type V	1 390		
	1 660	1435	1 720
	1 200	1430	1 790
Average	1 417	1432	1 755
Mil T-5608, Type V, Cl C	250		
	155	310	380
	177	265	390
Average	193	287	385
Mil T-5608, Type II, Cl E	1 000		
	750	1030	1 180
	760	1050	1 140
Average	837	1040	1 160
Mil T-5038, Type V	580		
	565		645
	615		640
Average	587		642
Mil W-27657, Type II	3 875		
	3 700		4 100
	3 900		4 050
Average	3 825		4 075

TABLE 13. (Concluded)

Sample Identification	KSC Seawater (lb)	Weatherometer (lb)	Unexposed (lb)
Mil W-4088, Type XIX	8 720		
	8 200		9 640
	9 060		10 160
Average	8 660		9 900
Mil W-4088, Type XXIII	9 550		
	9 000 ^a		9 960
	9 700 ^a		10 180
Average	9 417		10 070
Mil W-4088, Type XXVI	11 675 ^b		
	b		14 100
	b		13 900
			14 000

a. Stitches broke.

b. Severely abraded. Anchortie-down broke loose on rack at sea on two samples and abrasion visible on third sample with recorded value.

The parachute material appears to have followed the fouling process of other nontoxic material, i.e., the formation of a primary film composed at first of bacteria. This film is usually firmly attached within a 2 to 4 h period. Diatoms, a higher form of marine life, usually appear 24 h after the primary film has settled, followed by hydroids, etc.

Heterogeneous populations of bacteria excrete significant amounts of vitamins and larger concentrations are released when the bacteria die. This may account for the continued bacterial growth which may also be stimulated by the oxygen and a variety of amino acids released by diatoms. The diatoms in turn feed off the nutrients of the bacteria. Higher marine life, such as the barnacle, also share in this symbiotic cycle.

This fouling process probably contributed some effect on the parachute materials as noted in tensile strength and elongation testing. Since this test was conducted 640 m (700 yd) offshore in only 4.5 m (25 ft) of water, it may be construed (since no comparison is available) that this site is more richly endowed with bacteria than the deep ocean. Perhaps the sparseness of a primary microbial film in the deep ocean, coupled with rapid recovery of the parachute, would lessen the ocean fauna count appreciably. However, there are abnormal natural elements of the deep ocean which may affect the parachute integrity, such as tide and turbulence, and bloom of ocean marine organisms. The ocean turbulence may cause abrasion of parachute materials, while the tide may affect the amount of marine life present. The encounter of an ocean bloom of goose-neck barnacles could render a parachute unusable even though recovered within 4 h, due to the fact the parachute will be rolled and kept wet for several days, giving the attachment a chance to grow.

To get additional data from deep ocean water on parachute material, KSC agreed to attach selective parachute strips to the prototype of the SRB parachute scheduled to be "recovery-tested" at Port Everglade, Florida, in December 1977 (Table 14). The samples were thread tacked onto the prototype matching functional materials. The test site location was approximately 15 miles from shore.

The tests consisted of discharging the parachute into the water, recovering, and rolling the parachute onto a reel which simulates the actual recovery operation. The parachute and attached samples from MSFC were in the water approximately 4 h each test for a total of five tests or 20 h. The parachute and samples were brought back to KSC on the reel, dismounted, washed, and dried after 12 days.

The parachute strips were returned to MSFC for tensile strength and elongation testing. The tests were run 5 in./min with a gage length of 4 in. The samples of canopy parachute material, Nos. 1 through 7, were masking taped at each end to hold in the clevis clamps. These samples showed a higher breaking point than the rated strength. The load bearing parachute material, Nos. 8 through 11, was folded and stitched vertically at either end. These samples broke at the lower stitching line in each case and at a break point significantly lower than the rated strength which was attributed to the heavy stitching separating the fiber bundles which weakens the load capacity.

TABLE 14. PARACHUTE STRIPS TESTED AT PORT EVERGLADE
(DECEMBER 1977)

Type	Rated (lb)	Sea Test Break Point (lb, in.)	Elongation (%)	Application
Canopy Material				
MIL-W-83144 Type V, EH 33-3	1 500	1 745, 1 1/4	31.25	Horizontal Drogue Main
MIL-W-83144 Type V, EH 33-3	1 500	1 635, 1 1/8	28.12	
MIL-T-5038 Type V, EH 33-8	500	623, 1	25.0	Vertical Drogue Main
MIL-T-5038 Type V, EH 33-8	500	632, 13/16	20.25	
MIL-T-5608 Type V, EH 33-4	300	350, 11/16	17.25	Radial Main
MIL-T-5608 Type II, EH 33-6	1 000	1 088, 3/4	18.75	Radial Main

TABLE 14. (Concluded)

Type	Rated (lb)	Sea Test Break Point (lb, in.)	Elongation (%)	Application
Load Bearing Material				
MIL-W-4088 Type XIII, EH 33 6-A	6 500	6 000, 1 1/8	28.13	Pocket Bands, Drogue
MIL-W-4088 Type XIX, EH 33 8-A	10 000	8 500, 1 1/8	28.13	Radial Reinforcement, Drogue Vent and Skirt Bands, Main Riser
MIL-W-4088 Type XIX, EH 33 8-A	10 000	8 500, 1/16	24.25	
MIL-W-4088 Type XXVI EH 33 10-A	15 000	12 000, 1 1/8	28.13	Skirt Band, Drogue

Notes: Run 5 in./min
Gage length — 4 in.

All samples were sent to KEC in duplicate, some were lost in the testing.

I. Conclusions

1. Microorganisms were present on all surfaces examined by petri plate cultures or SEM stubs; however, the amount of fouling present clearly differed according to surface type.

2. It is interesting to note that although the Banana River revealed approximately ten-fold larger population of microorganisms than the ocean, quantitatively the ocean petri plates (7 day test) revealed more colonies than the 24 h river test due to the summer heat and bloom season of the ocean.

3. Primer and epoxy-coated metals, D6AC steel and 2219 aluminum, showed similar rate and extent of fouling with bacteria and diatoms.

4. Of the sealants, the silicone surface was found less susceptible to microbial colonization. The polysulfides (1422G and 1436G) were equally susceptible to fouling, showing heavy deposition of bacteria, diatoms, and protozoan species.

5. The rough surfaces of painted MSA-1, burned MSA-1, cork, burned cork, and flotation materials all revealed extensive fouling of bacteria, diatoms, and debris from both the ocean and dock sites. The pressure rinse after dock water recovery removed the accumulation but heavy growth remained.

6. Biofouling is a contributing factor in the corrosion of metals in the oceanic environment. The exact relationship between biofouling and corrosion is complex because certain surfaces attract one type of organism and not another. Tests have been run in the laboratory on material panels with artificial seawater over the same period as those exposed to the actual environment. It was noted that uncoated 7075 aluminum is highly conducive to marine organism buildup (much more than the other materials that were tested).

J. Recommendations

After being towed into dock site, the SRB should be removed as soon as possible from the water and cleaned. The booster should not be allowed to remain in the water at the dock longer than necessary since biological growth accumulated at this location was more abundant than the biological growth collected at the ocean exposure site.

IX. FLOTATION SYSTEM

The flotation system installed in the ITB serves a two-fold purpose. It provides the buoyancy necessary to support the ITB structure in the attitude necessary to provide proper exposure to SRB test systems, and it serves as a system test for proposed frustrum flotation. Light-weight, durability, and availability were baseline requirements for initial flotation material selection. The first material to be selected (polyurethane) met these requirements, but after extensive drop-testing and evaluation, was found to be structurally unstable at very low pressures; i.e. it disintegrated in vacuum tests. Polystyrene was selected as the design replacement. Both 16.01 and 32.02 kg/m³ (1 lb/ft³ and 2 lb/ft³) materials were procured, and subjected to repeated drop-tests to determine comparative durability. The 32.02 kg/m³ (2 lb/ft³) polystyrene was measurably superior to the 16.01 kg/m³ (1 lb/ft³) material from the standpoint of durability, and as a result was selected for frustrum (and ITB) flotation material application.

A. Discussion

Based on data from the original polyurethane materials tests, and prior to the vacuum degradation discovery, the foam bays in the ITB had been filled with precast urethane foam, cut to proper dimensions to approximately simulate frustrum flotation material design. The initial flotation test at the Saturn Dock on the Tennessee River resulted in a considerable departure from the intended flotation mode — instead of the desired log mode, the cylinder floated vertically and much too high. The ITB was recovered, the foam blocks were removed from the two inner bays, and it was refloated. This time it floated too low in the water. Again recovered, the flotation configuration was altered by adding an overlaying ring of polystyrene blocks, cut to proper contour and retained by nylon curtains (an integral part of the initial flotation system design). Refloated, the vehicle still adopted an undesirable attitude. Subsequent modifications in flotation placement were necessary before the desired configuration and buoyant attitude were achieved. All styrene block surfaces were sealed with a water-base paint (Sherwin-Williams Acrylic Latex), then bonded in place with U.S. Plywood Resorcinol water-proof adhesive. Following these preparations and a final securing of the nylon retention curtains, the ITB was transported to KSC to begin its 7 day ocean exposure test, to be followed by 84 h in harbor.

The vehicle was taken offshore and immersed in (relatively) unpolluted waters; after 168 h it was recovered, brought in, and again floated in the harbor. During this time the ITB was towed (for effect) for 2 miles at approximately 2 mph. Removed from the water, the ITB was returned to MSFC for disassembly and detailed examination.

B. Performance Assessment

There was no significant water logging of the flotation material. The ITB was floating at essentially the same level (and attitude) after the 252 h exposure as at the beginning. There was some apparent damage to the flotation blocks, attributable to the retention system. This damage occurred when the retention curtains and ribbons (designed to restrain blocks of the original flotation configuration) were over-extended to cover flotation elements of much greater volume. Had the flotation restraint system been redesigned to accommodate the altered flotation system, it is felt that this damage would have been minimized.

Excessive elongation of the nylon curtains and tie-down ribbons also played a role here, as it did in the preliminary drop tests. The nylon will elongate, loosen, and allow for excessive freedom of movement in the flotation blocks.

Removal of the flotation blocks, bonded together and to the ITB inner surface with adhesive, resulted in destruction of all pieces. The requirement for this interface bonding has been eliminated, and total reusability of all flotation material will be demonstrated in the next test.

C. Subsequent Flotation Retest

A 2 1/2 ft by 4 ft by 6 in. aluminum drop test panel used for impact testing of installed flotation materials in water drop tests was set up for flotation testing at KSC, with three significant departures from the original drop-test/flotation test configuration: (1) retention curtains were Dacron rather than nylon, (2) retention ties were also changed to Dacron, (3) approximately 2 in. were added to the flotation block thickness, necessitating a change in retention curtain design. Blocks were coated with a latex/acrylic paint and assembled into the panel recesses without bonding, either to the panel skin or block-to-block.

The panel was fitted with a ballast plate to hold the structure generally in a vertically bouyant attitude, and anchored in 25 ft of water, approximately 700 yd off shore at KSC, for 7 days. The panel and components survived virtually unaffected by saltwater or sea activity, indicating a successful demonstration of the proposed flotation system.

D. Conclusions

1. Configuration. An adequate SRB frustrum flotation configuration has been developed. This was satisfactorily demonstrated by local Tennessee River immersion and by the long term ocean exposure tests.

2. Material. The adequacy of the material in fulfilling the intended mission was evidenced by the apparent lack of water absorption and by the fact that, damaged as it was in the SRB test, it still offered total support to the host structures.

3. Retention System. This system will provide adequate restraint and support to the flotation blocks, provided that the curtains are redesigned to accommodate the new, effective configuration and provided that a material with less allowable elongation is selected for this application, as demonstrated with Dacron in the panel flotation test.

4. Flotation System. This system cannot be routinely disassembled and reused if the component blocks are bonded together and/or to the ITB structure, or to the frustrum surfaces. The flotation retest has shown this bonding to be unnecessary.

X. SRB JOINT SEAL AND PIN RETAINER BAND

A. ITB Clevis Joint Assembly

The D6AC steel ITB clevis joint was cleaned by three different methods before mating the male and female parts. The two sections were divided into three sections consisting of approximately 90, 90, and 180 degrees. The two clevis sections, male and female portions, were cleaned with a stainless steel brush over 90 degrees, Sumco 30 chemical cleaning over 90 degrees, and acetone solvent wiped clean over the remaining 180 degrees. After the various cleaning operations were completed, the male and female portions of the joint's unpainted surfaces were wiped with clean, dry rags to remove any residue that the cleaning operation had desposited on the metal surfaces. After the rag wipe was completed, the male portion of the clevis joint was coated with Braycote No. 137 preservative on the unpainted portion of the joint and also in the pin retainer holes. The female section of the clevis joint was also coated with Braycote No. 137 preservative in the inner portion of the section and also in the pin holes.

The O-ring was then placed in the O-ring groove in the female section of the joint. The two sections were then aligned and mated. The retainer pins were then inserted into the selected pin holes. The excess oil that was forced out of the pin holes during the pin insertion and the oil that had migrated onto the painted surfaces were then removed by wiping the exposed areas with an MEK dampened cloth until no visible evidence of oil remained on the exposed areas of the clevis joint.

B. Information

The inside wall area of the mated male and female clevis joint was cleaned using the same procedure used on the outer surface. After cleaning the surface on either side of the clevis joint and removing any oil or dust, the area was masked off to allow the Turco T522 Chem Mill maskant to be applied across the clevis area. This was done to seal the inner walls so the vacuum could be pulled on the Thiokol (EPDM rubber) boot when it was bonded over the outer surface of the clevis joint. The maskant was allowed to cure and then the Thiokol boot was prepared for installation. The boot was placed around the lower section of the ITB section and moved to the clevis area of the joint. In

moving the band in place, areas were touched with hands and needed to be wiped clean again to remove any hand oils or dust that could cause the adhesive that was to seal the boot along the upper and lower 1 in. bond area not to seal. These oils and dust were removed with a damp (MEK) cloth. The boot lip area, upper and lower edge, was inverted to allow for application of the adhesive on the boot lip area and also on the 1 in. wide bond strip area of the male and female ITB sections. The boot adhesive (Thiokol) UF3195 was then mixed and applied to the boot lip areas and the ITB boot bond lines. The boot was then rolled back to the normal position (Fig. 84). The excess adhesive was then wiped away and the boot lip portion pressed against the ITB surfaces to insure a tight fit and force out any air bubbles that might be trapped in the adhesive. A hypodermic needle was then inserted through the middle section of the band and into the clevis joint cavity to allow for a vacuum hose and pump to be connected to pull a vacuum on the clevis cavity (to hold the Thiokol boot in place while the adhesive was curing). The Thiokol boot developed a leak under vacuum in the area where the two ends of the rubber band were vulcanized together to form a continuous rubber band type configuration. Adhesive was repeatedly applied during the cure cycle to allow the vacuum to pull the adhesive along the vulcanized band joint until a buildup of adhesive was sufficient enough to stop the vacuum from pulling additional adhesive into the joint and the band sealed. The ITB assembly was moved to the paint shop area of Building 4760 to get sufficient heated area (70°F or above) for proper adhesive cure.

C. SRB Clevis Joint Assembly Test Panels

The 12 clevis joint test panels were assembled and sealed with the designated sealants, Dow Corning 93-076 on six clevis joint assemblies and Product Research 1422B on six clevis joint assemblies. These 12 assemblies have been divided into three groups consisting of two panels of each sealant in each group. The panels have been given a serial number for test identification purposes (Table 15).

The 12 clevis joint assemblies were painted again to apply the topcoat of paint over the sealants and seal any damaged area that was scratched or chipped during handling, assembly, and sealing operations. Eight of the clevis joint specimens were prepared to simulate the Thiokol seal concept. Four specimens were prepared to simulate no protection. All assemblies were then heated at atmospheric pressure to the temperature expected during vehicle reentry.



Figure 84. Applying the Thiokol boot to the ITB.

TABLE 15. CLEVIS JOINT TEST ASSEMBLY PANELS

	Sealant	Test Site
Group 1 — Steel Male — Aluminum Female		
SN No. 1 XX1-XX1 to 1A-1A	Dow Corning	Ocean
SN No. 2 XX3-XX3 to 3A-3A	Dow Corning	Beach
Steel Male — Steel Female		
SN No. 3 X2-X2 to B2-B2	Product Research	Ocean
SN No. 4 X4-X4 to B4-B4	Product Research	Beach
Group 2 — Steel Male — Steel Female		
SN No. 5 X1-X1 to B1-B1	Dow Corning	Ocean
SN No. 6 X3-X3 to B3-B3	Dow Corning	Beach
Steel Male — Aluminum Female		
SN No. 7 XX2-XX2 to 2A-2A	Product Research	Ocean
SN No. 8 XX4-XX4 to 4A-4A	Product Research	Beach
Group 3 — Steel Male — Aluminum Female		
SN No. 10 XX5-XX5 to 5A-5A	Dow Corning	Beach
SN No. 11 X5-X5 to B5-B5	Dow Corning	Ocean
Steel Male — Steel Female		
SN No. 9 XX6-XX6 to 6A-6A	Product Research	Ocean
SN No. 12 X6-X6 to B6-B6	Product Research	Beach

Each group consists of four steel male members mated to two aluminum female and two steel female members. The serial numbers and sealants are as follows with the subassembly part numbers mated to subassembly part numbers: Group No. 1/No Protection, Group No. 2/Limited Protection, and Group No. 3/Maximum Protection.

The configurations of the assemblies are as follows:

1. Group No. 1 — Male and female numbers are not painted on inserted area, the pin hole is not painted, and no Braycote is sprayed on clevis joints. The fasteners are sealed with sealants.

2. Group No. 2 — Male and female numbers are not painted on inserted area, the pin hole is not painted; however, Braycote is sprayed on inserted area (male and female) and in pin hole, and the outside is sealed with Thiokol seal configuration and Chem Mill maskant on back side of clevis joints.

3. Group No. 3 — Male and female numbers are painted on inserted areas, the inside pin hole is not painted, Braycote is on clevis (male and female) and in pinhole, and MIL-P-8116 zinc chrome putty is placed along fillet area and Chem Mill maskant over the back side of clevis joints.

Six clevis joint specimens were exposed to the ocean and KSC harbor environment for a total of 10 days and were cleaned, using the following "standard" cleaning cycle:

1. Potable water rinse
2. High pressure hot water (200 psi, 175°F), detergent
3. High pressure hot water rinse
4. Potable water rinse
5. DI water rinse.

In addition to extensive corroded areas on unpainted areas within the joint seal, an abundance of plant and animal marine growth was present on both painted and unpainted surfaces (Fig. 85).

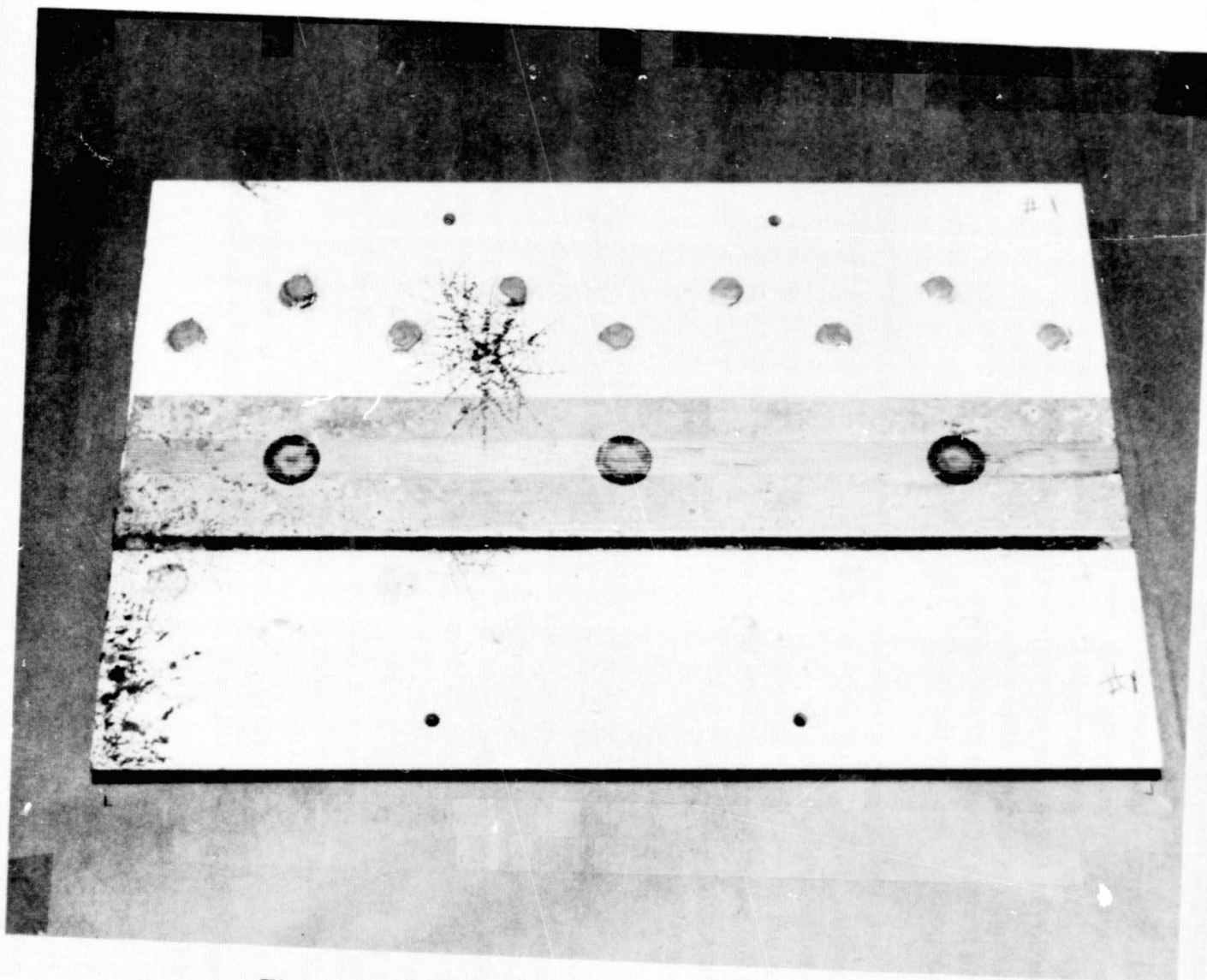


Figure 85. Clevis joint sample showing marine growth.

Six of the detergent cleaned clevis joint samples had additional mechanical cleaning to remove rust scale and corrosion on the unpainted portion of the clevis joint. A rotary wire brush with a variable speed drill motor was used. A 101.60 mm (4 in.) diameter brush was used to remove the bulk of the rust from the outer portions of the joint but left traces of rust in the pitted areas of the joint. The larger diameter 152.40 mm (6 in.) brush used to clean the inside portion of the female joint removed a considerable amount of the rust and corrosion, but was not effective along the side wall of the clevis joint. The male and female portions of Group Nos. 1, 2, and 3 were chemically cleaned with Sumco 30 to remove the rust and corrosion from the pitted areas.

Preliminary evaluation of results indicates effective removal of marine growth. Effective removal of the salt film on the surface was also shown by results obtained with the Orion chloride ion probe. Chloride ion concentration on wet corroded surfaces after the last potable water rinse was 40 to 60 ppm. This reading dropped to below 10 ppm after DI water rinse and is regarded as particularly illustrative of the benefits to be expected from a routine, final DI water rinse.

All twelve clevis joint assemblies were carefully inspected. The six assemblies that had Dow Corning 93-076 sealant on the stainless steel fastener nuts did not have adequate adhesion and needed to be removed as best as possible and recleaned. The procedure used was (1) to file off the sharp edges of the fastener that protruded through the nut and rub the area around the nut with steel wool to roughen up the painted surface, (2) brush clean the nut and painted area with MEK and then wipe with a damp (MEK) kimwipe to remove any residue, (3) allow to air dry and then prime with Dow Corning 1203 primer, and (4) wait 10 min and reprime with Dow Corning 1203 primer and let dry for 24 h before resealing with Dow Corning 93-076 sealer.

These six clevis joints were resealed with DC 93-076 and the sealer exhibited better adhesion to the painted surface and also on the stainless steel nuts.

The Thiokol Seal configuration boot was applied with Thiokol adhesive UF3195 and under a vacuum bag on panel Nos. 5 through 11. Panel No. 12 had the boot applied using the hypodermic needle inserted through the boot and a vacuum pulled through needle to allow the adhesive to cure.

Six clevis joint samples were returned from the KSC ocean exposure test and the assemblies have been broken down into subassemblies and photographed. Two of these samples had no protection in the joint area and showed considerable corrosion and rust (Fig. 86). Two other samples had the Thiokol boot configuration and Chem Mill maskant on the bottom side. These two samples had Braycote oil in the joint area but showed considerable corrosion and rust (Fig. 87). The two remaining samples were painted in the joint (Fig. 88), had Braycote oil over the paint with Thiokol boot on outer surface, and had Chem Mill maskant on the bottom side. These two samples were the best of the six but showed some corrosion and rust in areas.

D. Assessment of Performance

The Turco T522 Chem Mill maskant did not show any evidence of moisture entry into the clevis joint. The maskant was easily removed by cutting across and peeling from the surface.

The Thiokol boot required an air operated chisel to break the adhesive bond. No evidence of leakage was detected along the bond line, but there was adhesive and EPDM rubber residue remaining along the bond surface due to the air chisel removal of the boot.

The retainer pins were difficult to remove due to the rust stains and the egg shape alignment of the two sections. The last pin removed required a pin puller fixture made to pull the pin from the hole. This pin galled in the hole when trying to remove the pin with the jackscrew.

The upper section was lifted with a crane to disengage the two sections. The lower section did not have sufficient weight to unmate the two areas. With the upper section lifted slightly, the lower section required striking the lower clevis joint with a rawhide mallet to disengage from the upper section.

E. Conclusions

The ITB clevis joint did have small amounts of moisture inside the clevis joint area. There was rust and rust stains present inside the joint. The bare areas of the clevis joint that had no preservative oil showed considerably more corrosion and rust than on the areas where preservative oil had been applied. The rust and rust stains were more easily removed from the oil coated surfaces.

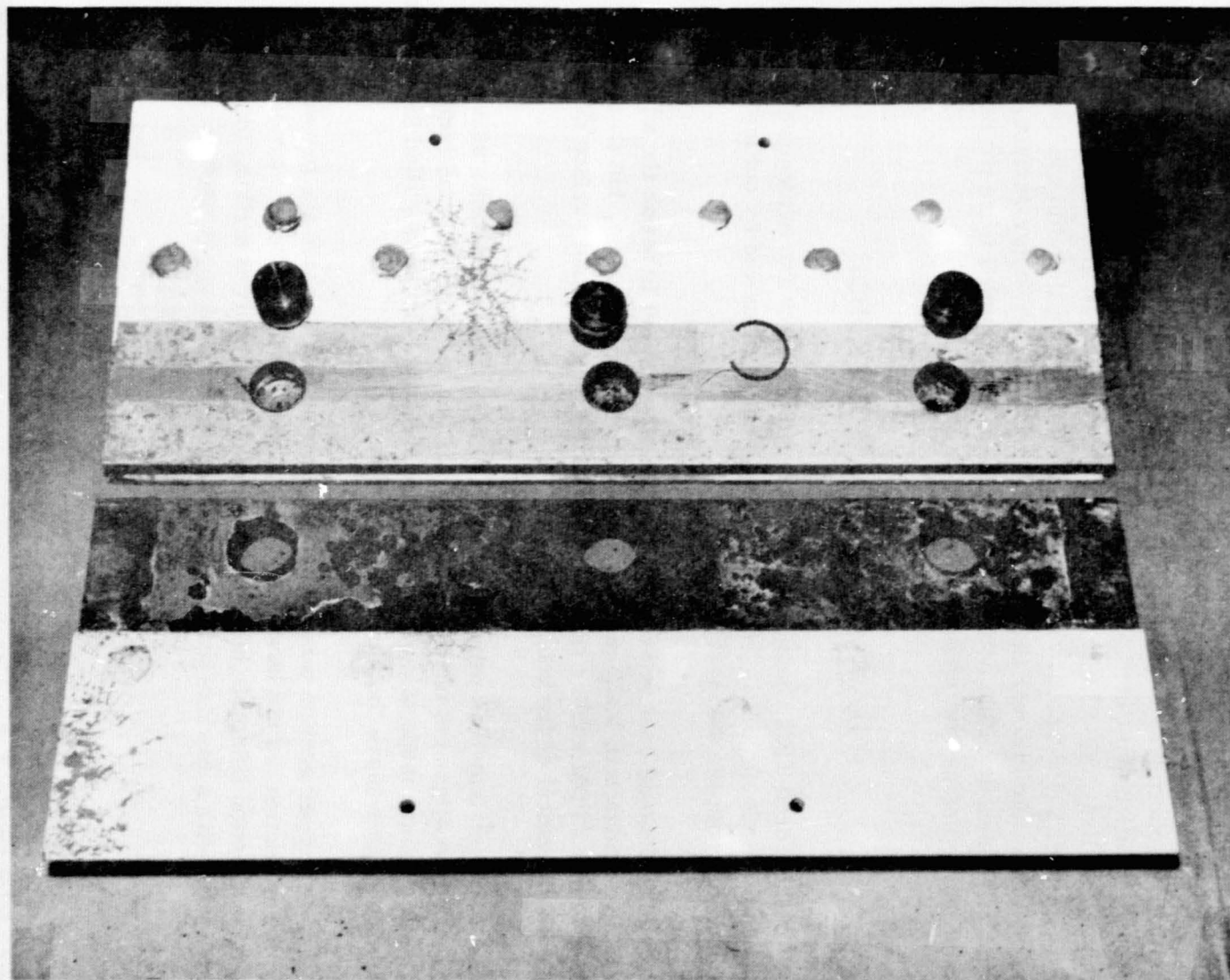


Figure 86. Clevis joint sample without protection (i.e., lacking paint, Braycote oil, and Thiokol boot).

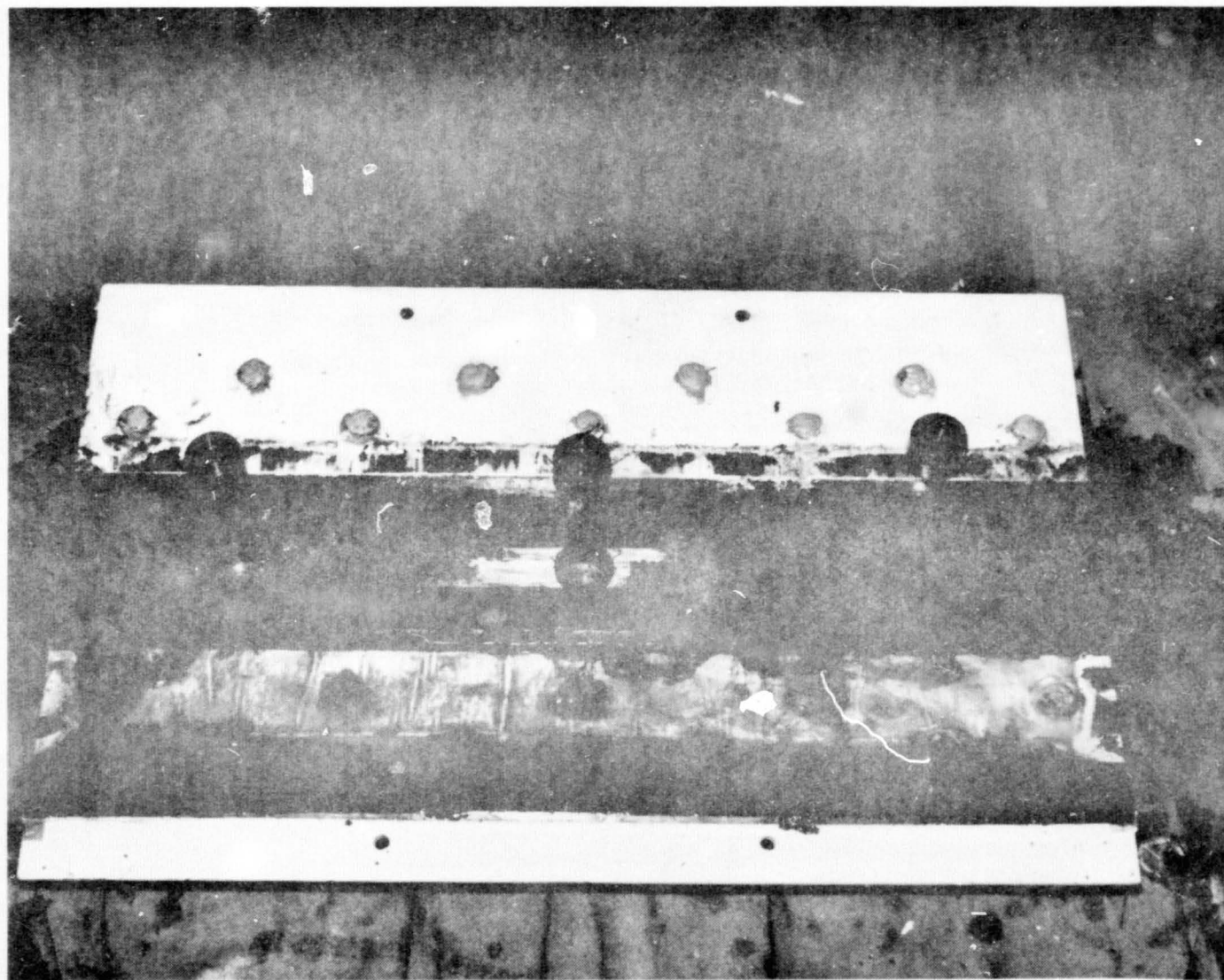


Figure 87. Clevis joint sample with Thiokol boot and Braycote oil.

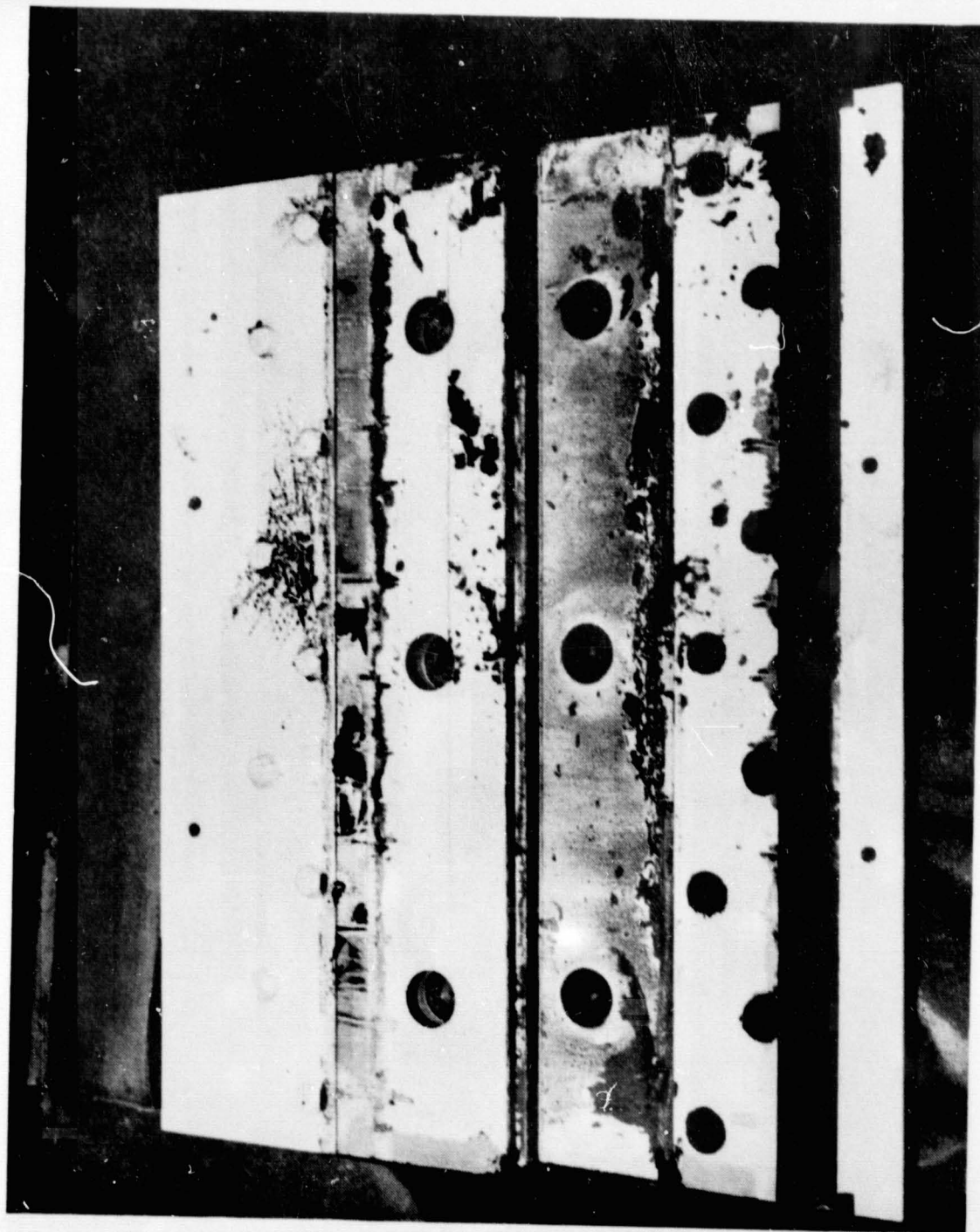


Figure 88. Clevis joint with paint.

There was excessive adhesive material present inside the boot area where the vacuum had migrated the adhesive during boot bonding and also in the spare pin holes that had no pins inserted. (Approximately one-half of the pin holes had retainer pins inserted for this test program, see Figure 89.)

The clevis joint test specimens had considerable rust present inside the clevis joint and on the outer metal surfaces. The steel members required considerable mechanical cleaning to remove the rust scale. The aluminum members required considerable mechanical cleaning to remove the corrosion from the metal. Chemical cleaning was required to remove the rust and corrosion that had pitted the two metals.

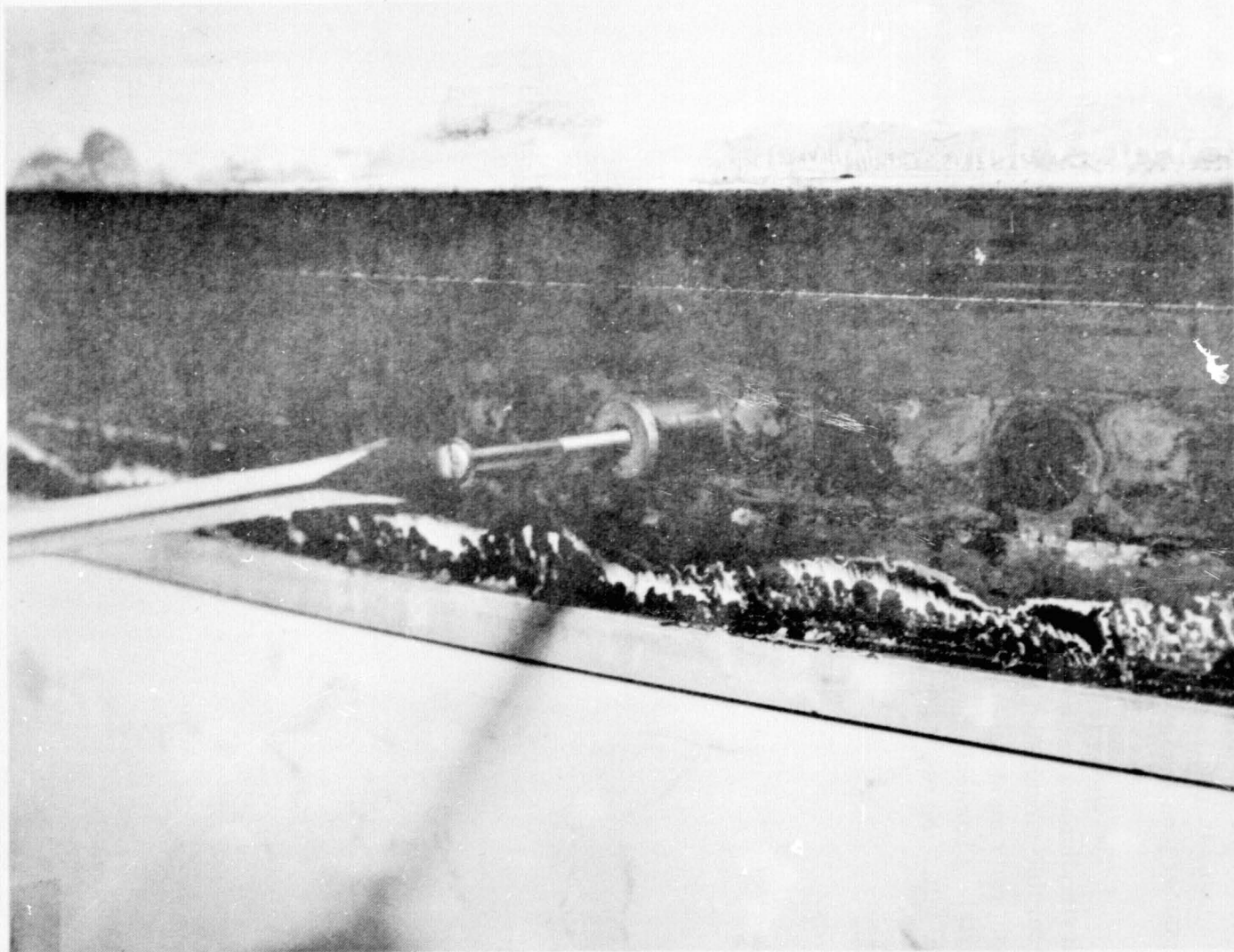


Figure 89. ITB clevis joint showing pin removal.

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XI. NONDESTRUCTIVE EVALUATION

A. Discussion of Techniques

The success of the SRB is highly dependent upon the effectiveness of the protective coatings and sealants to prevent seawater corrosion of the basic structural elements. Failure of these coatings and sealants to effectively perform this function will substantially shorten the structures life or will necessitate timely repair of degraded areas. Nondestructive evaluation (NDE) techniques were selected based on their potential to detect the failure of the coating/sealants or which might detect the incursion of seawater into hidden areas of the structure as a result of sealant failures.

The most basic form of NDE, visual examination, was chosen as the first technique to be employed. Careful visual examination will detect cracking of surface coatings and bulging of sealant areas. Ultrasonics was selected to detect bondline failures at sealed fastener joints and to detect potential corrosion in fastener holes. Radiography was selected to detect incursion of seawater between sealed surfaces or in fastener holes.

The initial evaluation of these techniques was conducted on bench samples (see Fig. 90 which simulated the material couples and sealants being proposed for SRB). The samples were fabricated using proposed SRB processes and submitted for baseline NDE. Each sample was photographically documented and X-rayed. An ultrasonic bond inspection was performed using immersion pulse-echo techniques, schematically shown in Figure 91. A baseline ultrasonic scan of corner sharpness for each fastener hole was also performed. This corner sharpness could be used as a basis for evaluating corrosion of the fastener hole which would blunt the sharpness and change the ultrasonic reflectivity.

After baseline inspection, the samples were subjected to simulation cycles with environmental parameters similar to the boost, reentry, and recovery phases of the SRB profile. Between each simulated cycle, the specimens were resubmitted for NDE.

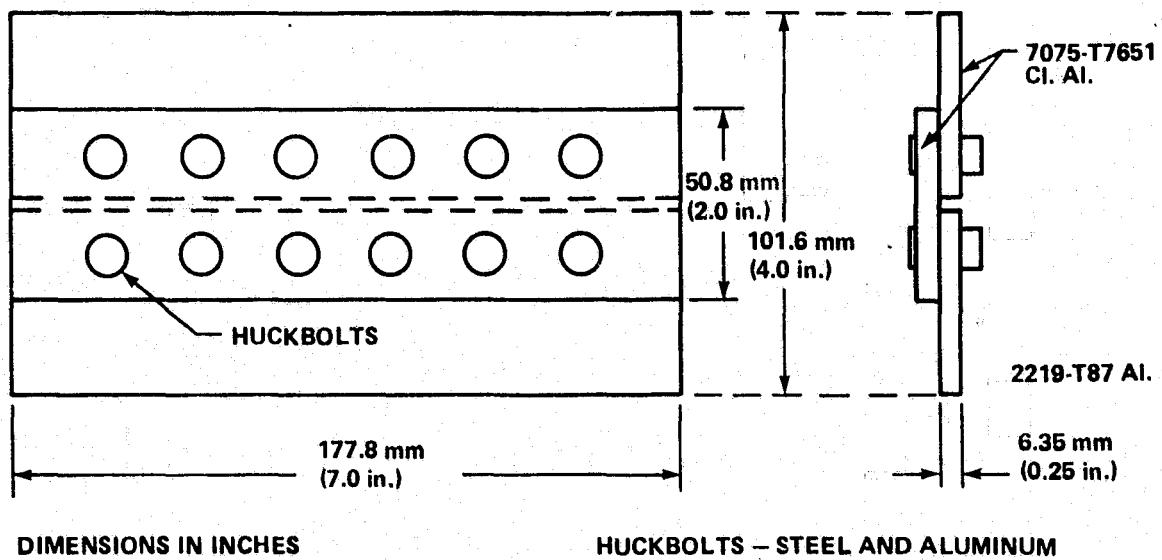


Figure 90. Bench samples.

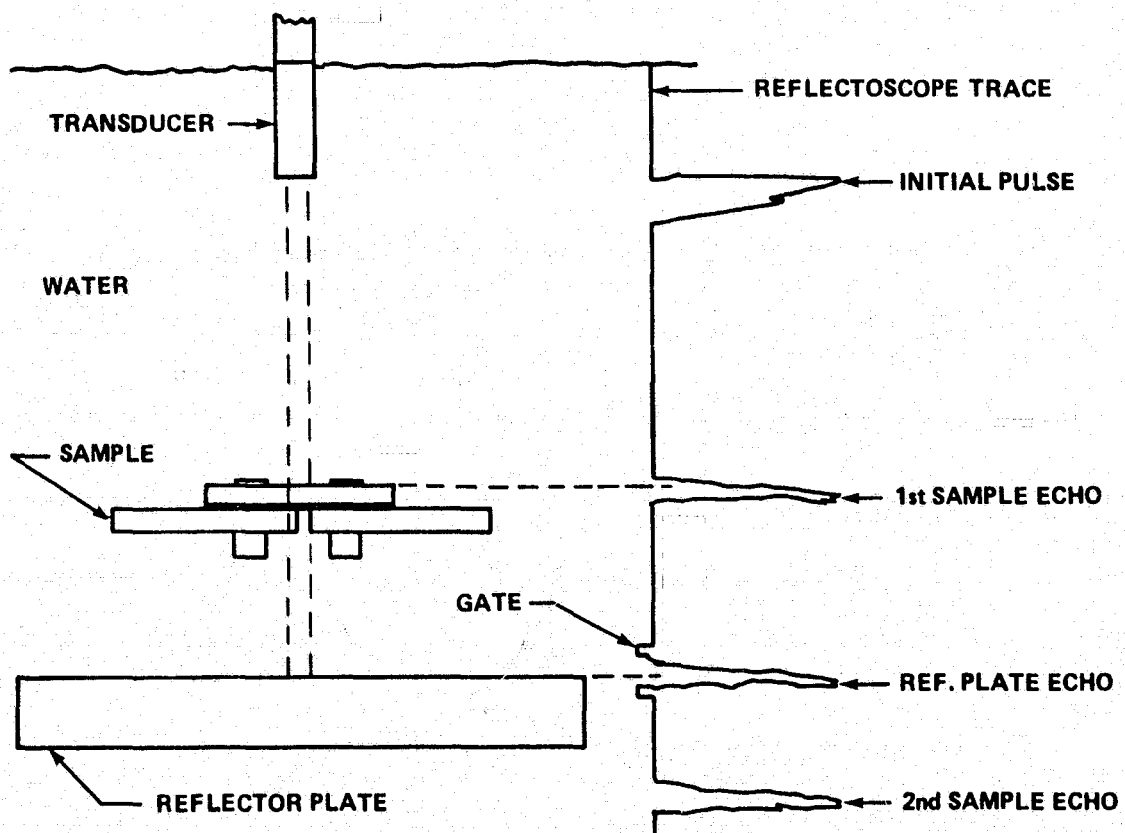


Figure 91. Ultrasonic bond technique.

B. Conclusions

Substantial degradation was noted between simulation cycles in the visual appearance of the specimens. Cracking of paint over fastener heads was extensive on most candidate sealants. Substantial apparent degradation was noted in the bond and corner reflectivity tests. However, teardown of selected specimens during the test did not show the disbonding or corner blunting that would have been anticipated based on the ultrasonic test results. It appears that these results were due to changes in the acoustical properties of the sealant, rather than to the presence of disbonding or corrosion. In fact, the variation in the external appearance of the sealant/coating seems to correlate with the ultrasonic degradation. The only corrosion noted on these specimens occurred in the areas on and around fastener ends where breakdown of the sealant/coating was visually noted.

XII. ELECTRICAL SUBSYSTEMS

The electrical subsystem was a watertight black box/cable test assembly consisting of a simulated black box with three connectors and mating cables (Fig. 92). The black box test results are covered in this section. The watertight cable test results are covered in Section XIII.

A. Discussion of the Simulated Electrical Black Box

The test article was fabricated from 6061 T6 aluminum. The surface was Alodine and painted in accordance with 10A00528 (Protective Finishes for Aluminum and Steel Alloys Subject to Seawater Exposure) using gloss black paint. Connector mounting holes were painted through and on the inside to a point far enough to allow seating of the O-ring on the painted surface, but not so far as to interfere with connector flange grounding. The inside surface around the connector mounting hole had previously been milled down in an effort to make the painted portion flush with the unpainted surface. The ends of the box were grooved to accommodate O-rings. The end plates were assembled to the box using 12 stainless steel screws for each. The connectors installed in the black box consisted of three watertight connectors in accordance with 16A-02980 (Connectors, Electrical, Circular Miniature, Underwater, Specification Control Drawing For) wired with polytetrafluoroethylene insulated, nickel-coated copper wire in accordance with 40M39513B (Wire, Electrical, Hook Up, General Specification For). Connector jam nuts were torqued to the values specified in 16A02980. Sealant (PR 1422) was applied to the large connector jam nut, the end plate screws, and the interface between end plates and box in accordance with 10A00526 (Sealing of Faying Surfaces). The watertight black box/cable test assembly was subjected to six test cycles in-house by EC42 before delivery to Materials and Processes Laboratory for installation on the ITB. During the in-house testing, a paint blister developed on the box, and after the fifth cycle the spot was repainted by the MSFC paint shop (Figs. 92, 93, and 94). A test cycle consisted of 30 min in a vacuum chamber, 48 h submerged in a 3.5 percent saltwater solution at 60 psig, and 24 h subjected to 5 percent salt spray solution. Insulation resistance readings were taken periodically.

Upon completion of evaluation after being returned from ocean exposure on the ITB, the test article was prepared for the basket test by stripping, refinishing, and repainting the cylinder portion and providing new end plates for

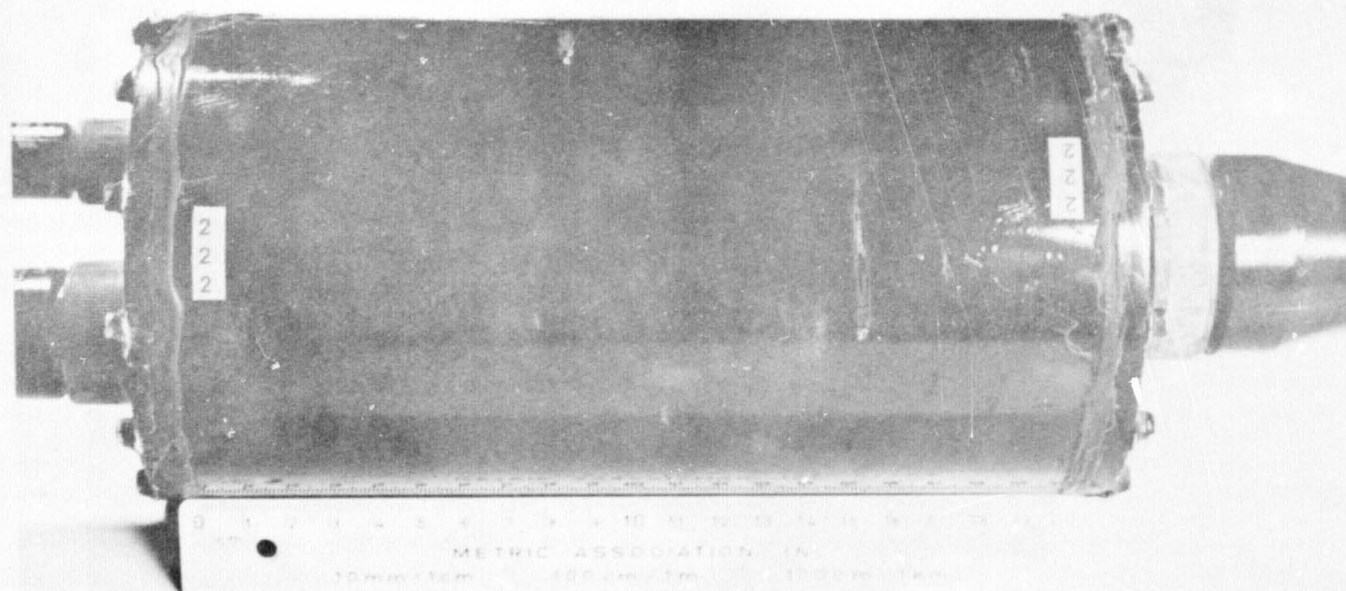


Figure 92. Watertight black box/ cable assembly No. 2 (after five test cycles and refurbishment, plus one additional test cycle).

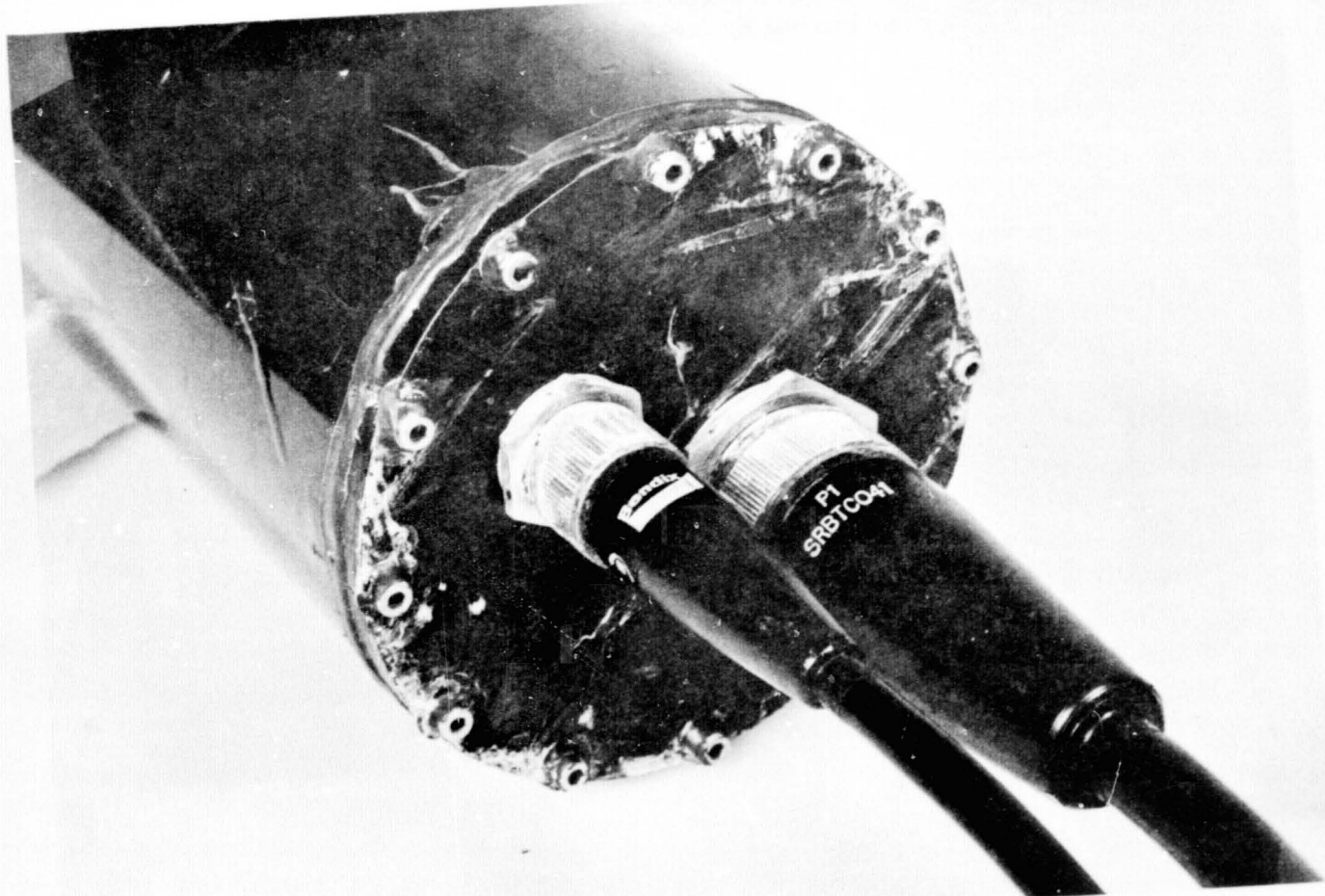


Figure 93. SRB watertight black box/ cable assembly No. 2 (end view after three test cycles).

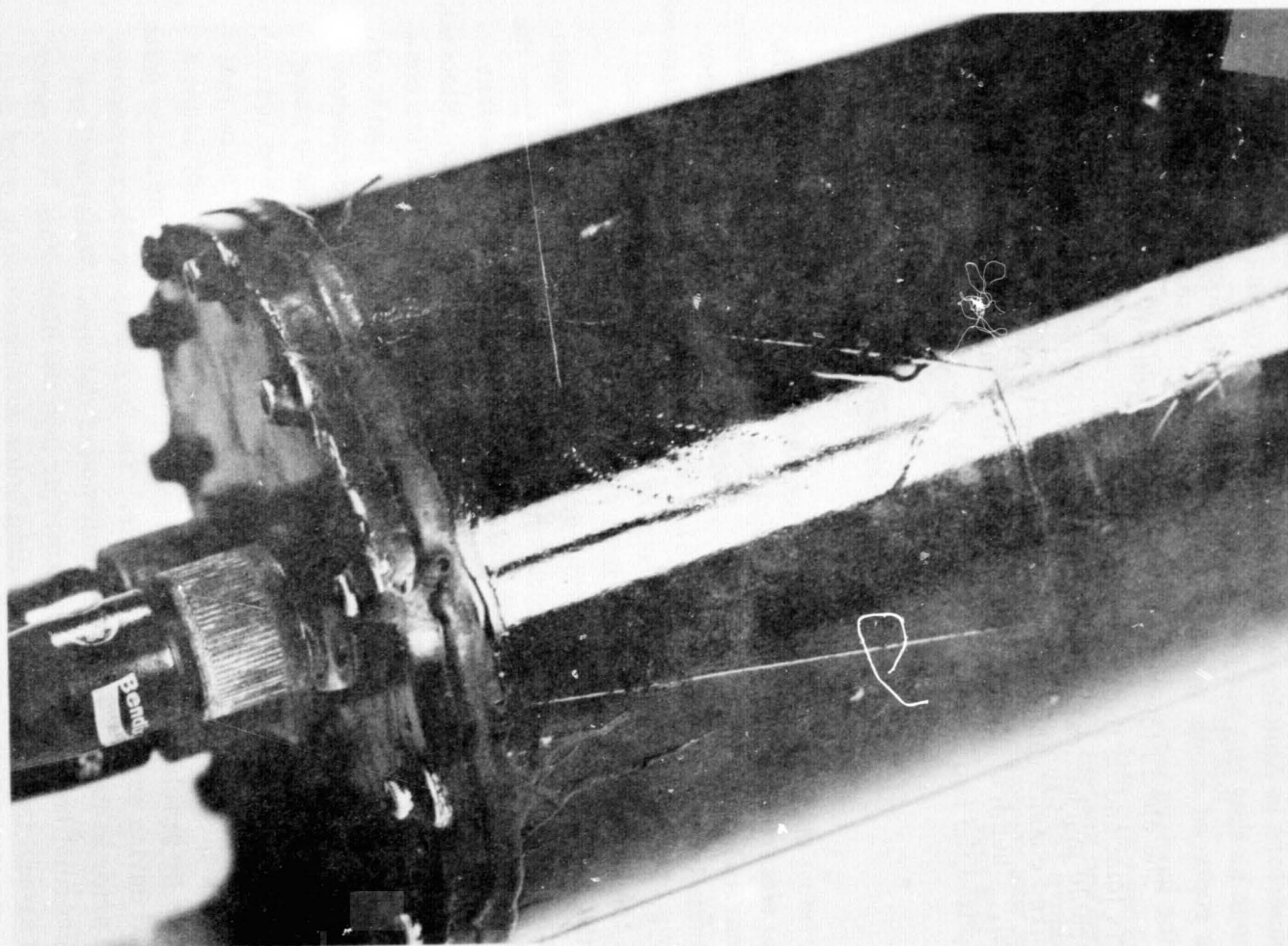
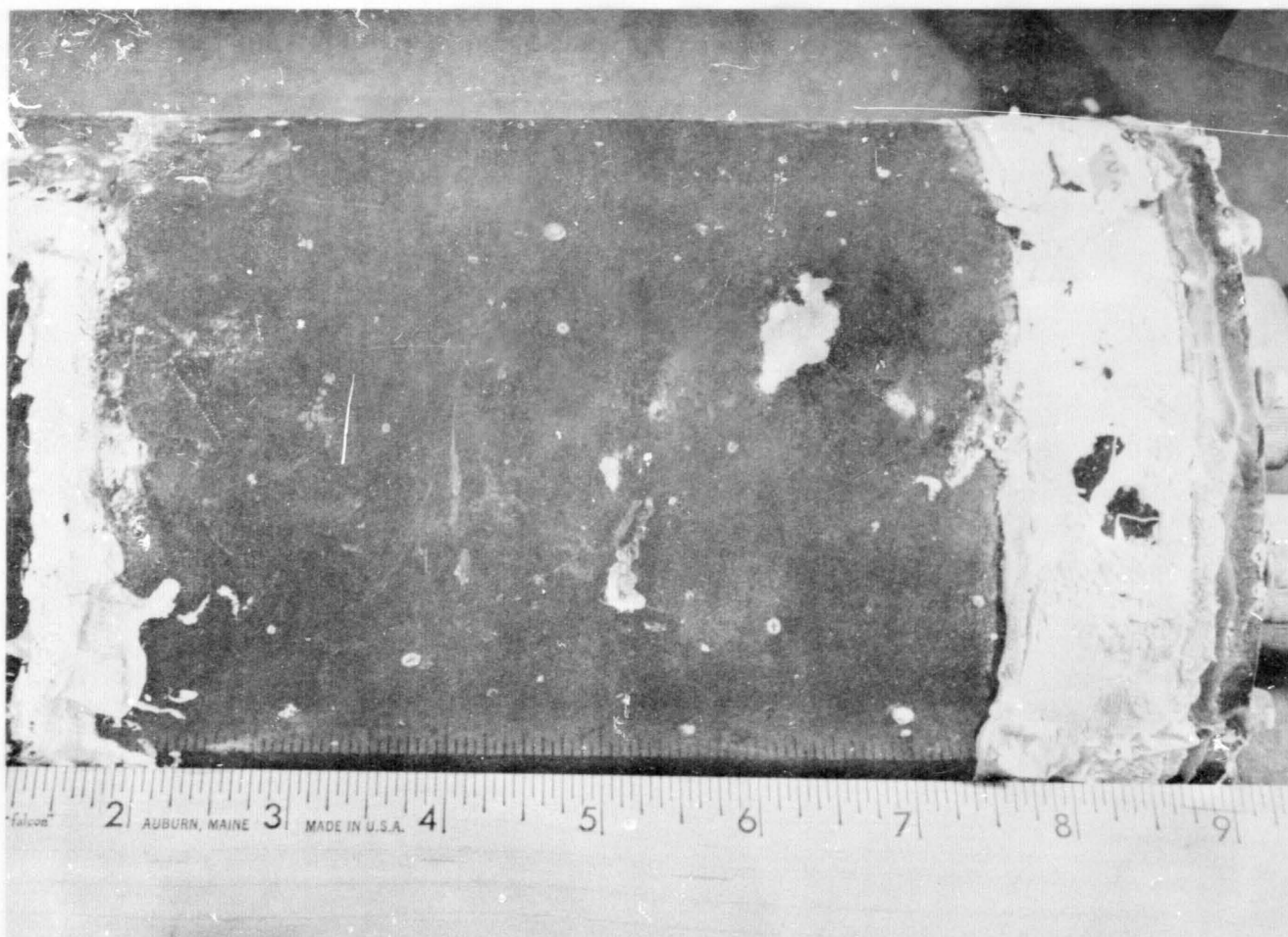


Figure 94. SRB watertight black box/ cable assembly No. 2 (closeup of patched area after five test cycles and refurbishment, plus one additional test cycle).

the black box. The connector mounting holes were prepared in accordance with Figure 1 of MSFC Procedure 16A02058 (Installation of Jam-Nut and Flange Mounted Connectors in Aluminum Watertight Black Box Assemblies) and not painted through as they had been on the ITB test article. The internal wiring harness was replaced except for the NAJ7H24-61P connector. Eight wires in the new wiring harness were silver plated copper insulated with TFE. The remaining wires were nickel plated copper with TFE insulation. The connectors were installed and sealant (PR 1422) applied in accordance with Figure 1 of MSFC Procedure 16A02058. Except for the connector installation procedure, the black box was assembled and cables attached in the same manner as was done for the ITB test.

B. Performance Assessment

After being subjected to six test cycles and ocean exposure on the ITB, there were no electrical insulation resistance failures of the test article. However, some corrosion and barnacles were observed. Some spots of corrosion were on the main body of the box (Fig. 95). Also some barnacles were observed on the box (Fig. 96). The large white area at the end of the box is a sealant used between the box and mounting brackets. Some corrosion spots were observed on the ends of the box around the connector jam nuts and screw heads (Figs. 97 and 98). The end with the two smaller connectors was worse than the end with the large connector. This was expected, however, since no sealant was used on the smaller connector jam nuts. When the end plates were removed, some salt crystals were observed around the inside flanges of the smaller connectors, particularly the No. 16 shell size (Figs. 99 and 100). The inside of the box appeared to be in good shape except for the area around the connector flanges. The inside of the No. 16 shell size connector appeared to have some slight traces of mineral deposits beyond the O-ring (Fig. 101). Figure 102 illustrates the connector interface sealing mechanism. It should be noted that even if saltwater leaked into the connector interface it would likely not cause a functional failure or preclude the continued reuse of the black box since the units are deenergized during exposure to saltwater. The hermetic sealed connectors can be washed prior to reuse with little likelihood of damage. Water will not leak through a normal hermetic sealed connector into the black box. Corrosion damage in and around the connector mounting holes was revealed in more detail after the paint was removed from the end plates (Figs. 103 and 104).



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Figure 95. SRB watertight black box/cable assembly No. 2 after ITB testing.

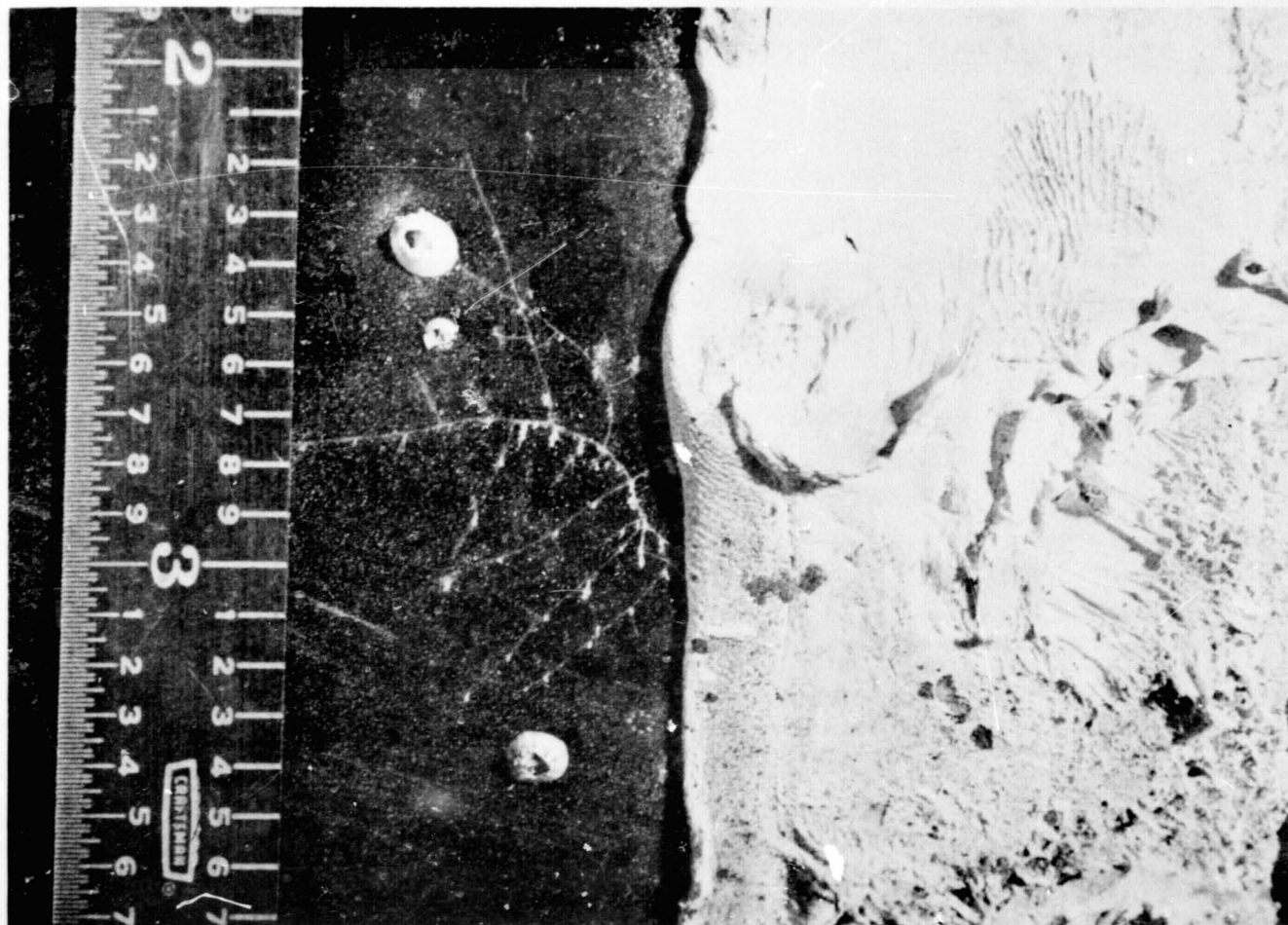


Figure 96. SRB watertight black box/cable assembly No. 2 after ITB testing (note barnacles).

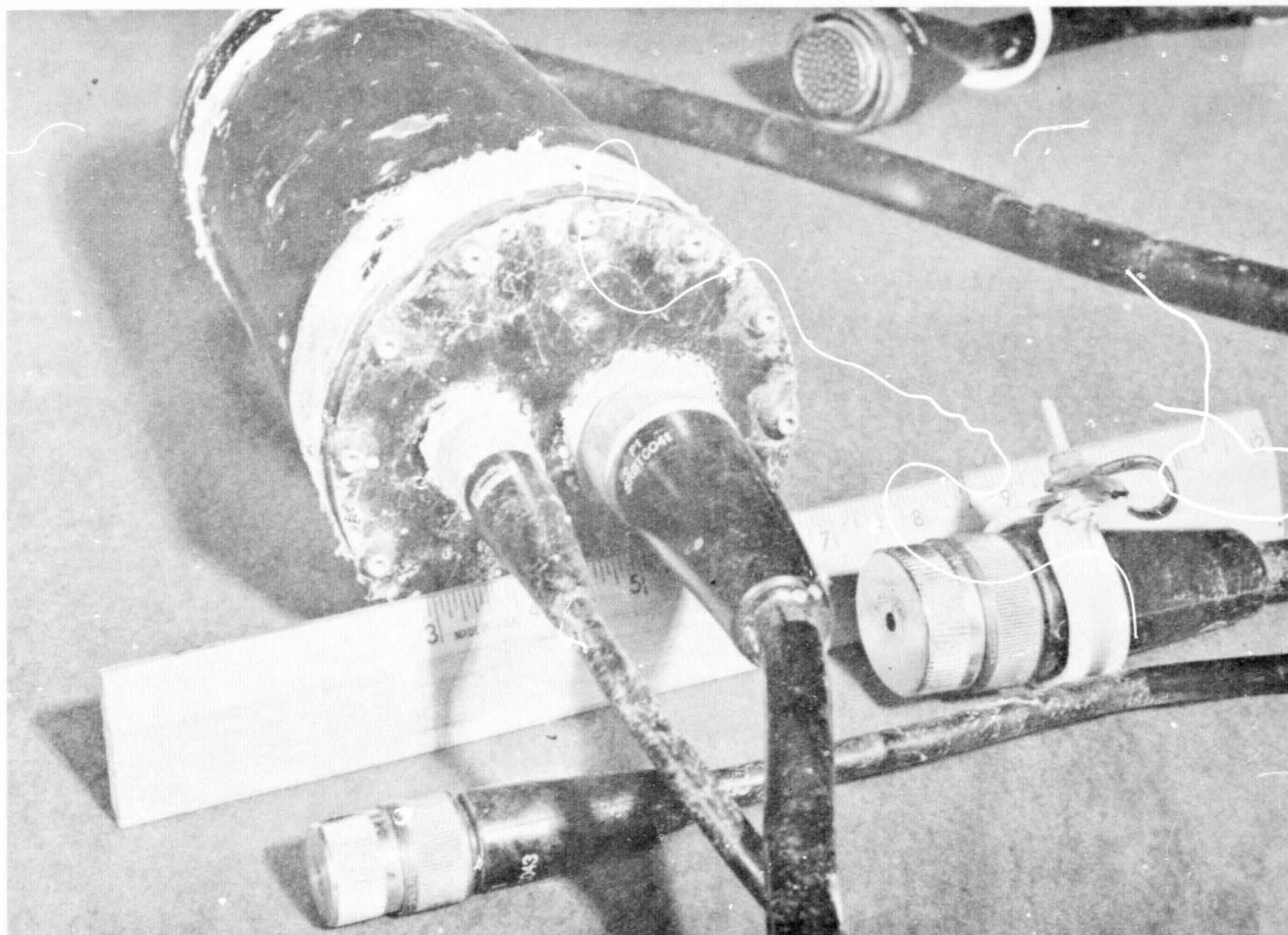


Figure 97. SRB watertight black box/ cable assembly No. 2 after ITB testing
(note corrosion around jam nuts).

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Figure 98. SRB watertight black box/cable assembly No. 2 after ITB testing (note corrosion around screw heads).



Figure 99. SRB watertight black box/cable assembly No. 2 after ITB testing (inside end plate).



Figure 100. SRB watertight black box/cable assembly No. 2 after ITB testing (inside end plate, closeup).

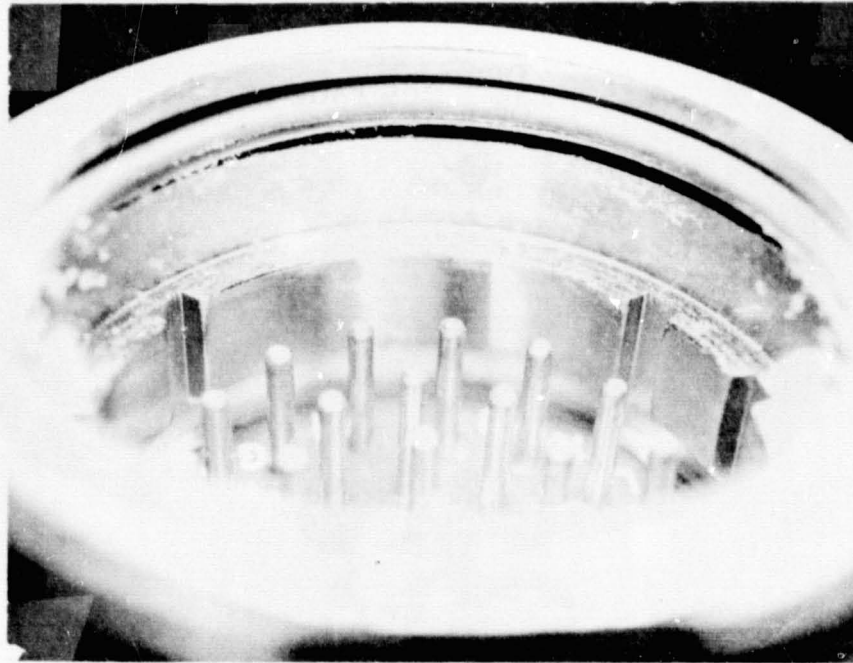


Figure 101. SRB watertight black box/ cable assembly No. 2 after ITB testing (inside view of connector).

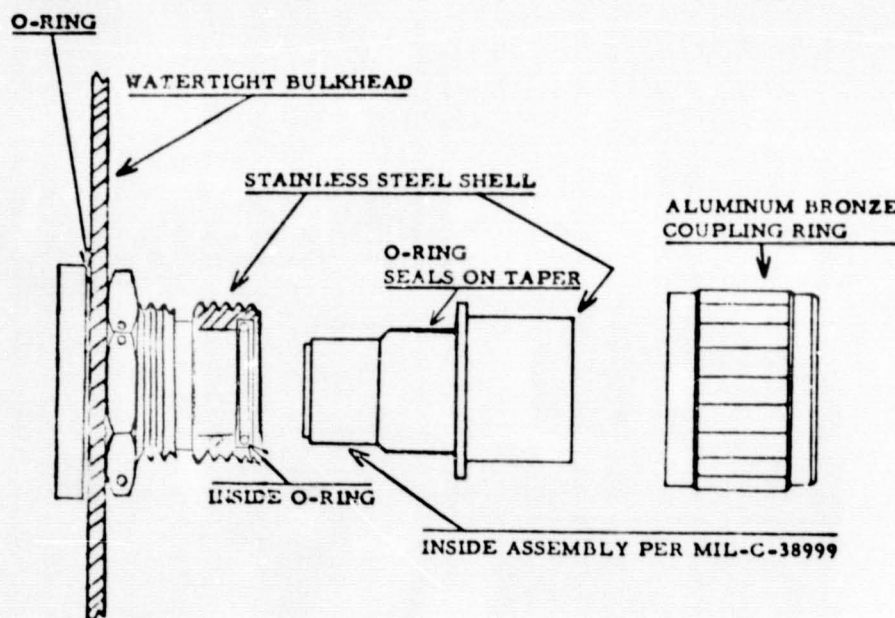
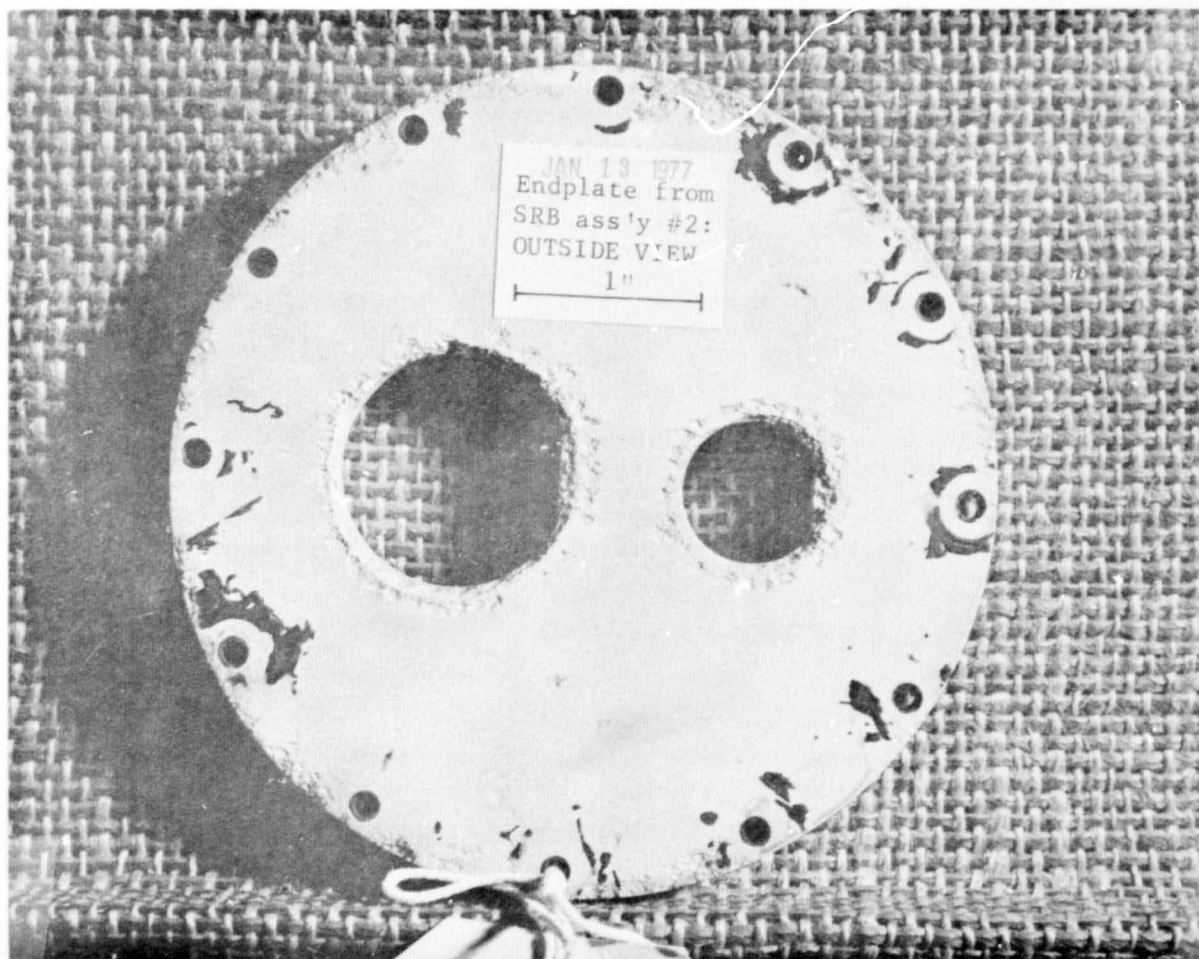


Figure 102. The connector interface sealing mechanism.



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Figure 103. End plate (Nos. 16 and 8 connector mounting holes) from SRB watertight black box/cable assembly No. 2 after paint removal.

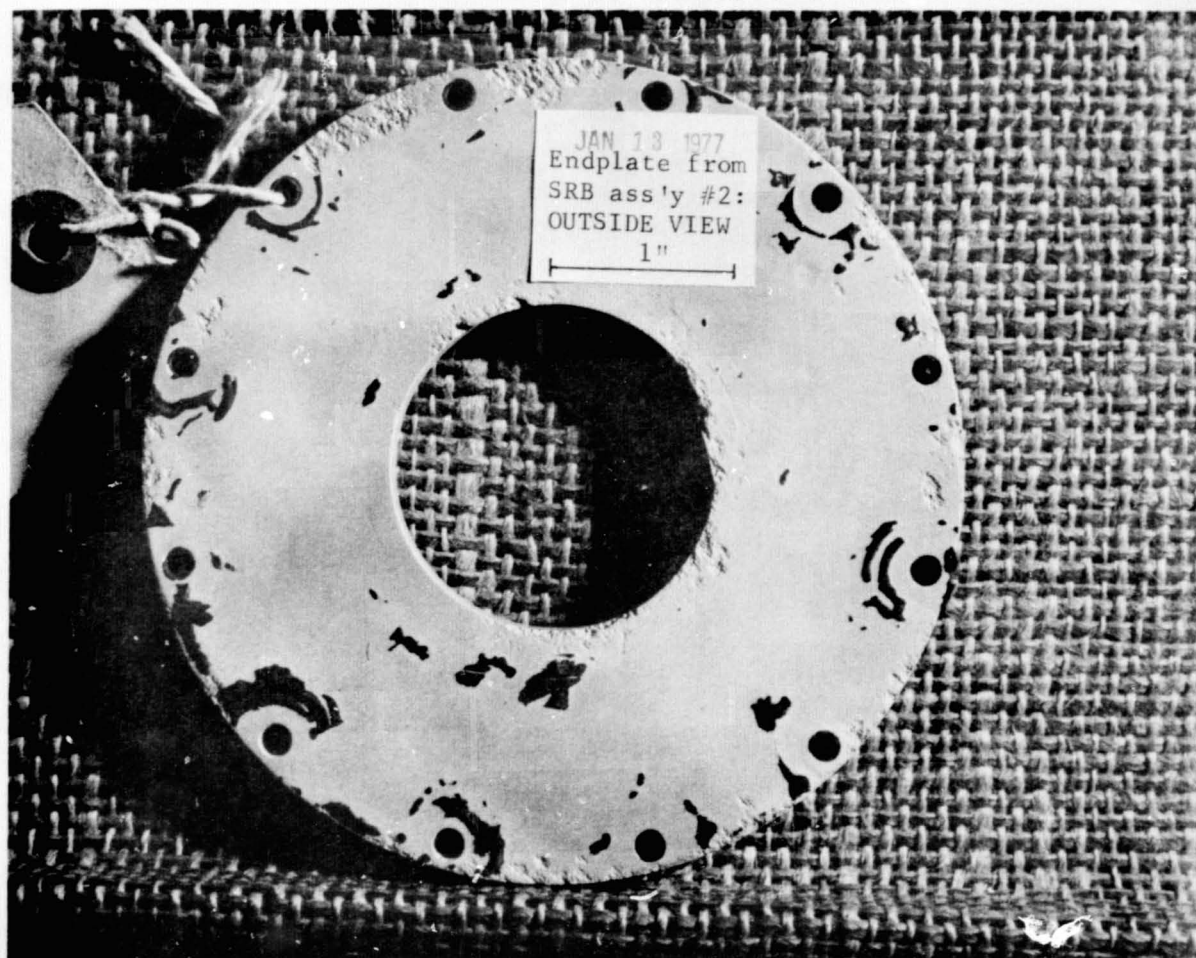


Figure 104. End plate (No. 24 connector mounting hole) from SRB watertight black box/cable assembly No. 2 after paint removal.

After being subjected to the basket test, there were no insulation resistance failures of the test article (all readings above 20 000 M Ω). The outside of the test article was in good condition except a few spots where the paint was scraped off due to handling and strapping into the basket (Fig. 105). Very little corrosion was observed. However, with longer exposure serious corrosion probably would have developed in the spots where the paint was scraped off. There was no evidence of leakage to the inside of the connector mounting holes, inside the box, or connector interfaces. Sealant was observed in and around the outside edge of the connector mounting holes and in some of the connector threads. This resulted from use of the improved sealing technique (Fig. 105). No evidence of any damage or degradation of either the silver plated or nickel plated harness wires was observed.

C. Conclusions

Although no electrical failures occurred, the corrosion in and around the connector mounting holes where no sealant was used is considered unacceptable and would likely cause problems prior to 20 missions. The connector mounting hole where the sealant was used exhibited less corrosion damage than those where no sealant was used; however, it is not certain that 20 mission usage can be expected even with the use of sealant. It seems reasonable to conclude that sealant applied around and over the connector jam nuts does provide additional protection; however, it is less than 100 percent effective.

Based on present test results and factors (such as the lack of a practical method to assure that no pinholes exist in the sealant or paint, chipping or scratching of paint during assembly and handling and length of time in storage), improved protection methods are required on aluminum boxes to assure 20 mission usage without meticulous inspection, refurbishment, touchup, and repair. It is doubtful that an inspection can be developed to detect all corrosion because some instances of corrosion under paint and sealant have been observed upon removal of the paint.

The absence of any evidence of leakage to the inside of the connector mounting holes or to the inside of the box after summer of 1977 basket tests indicates that the improved sealing technique as delineated by Figure 1 of MSFC Procedure 16A01058 is substantially more effective than the method previously used. Although, the method used to strap the simulated black box in the test basket may not be typical of mounting methods on the SRB, the fact that the paint was scraped in spots does indicate this susceptibility from normal handling and installation on the SRB.

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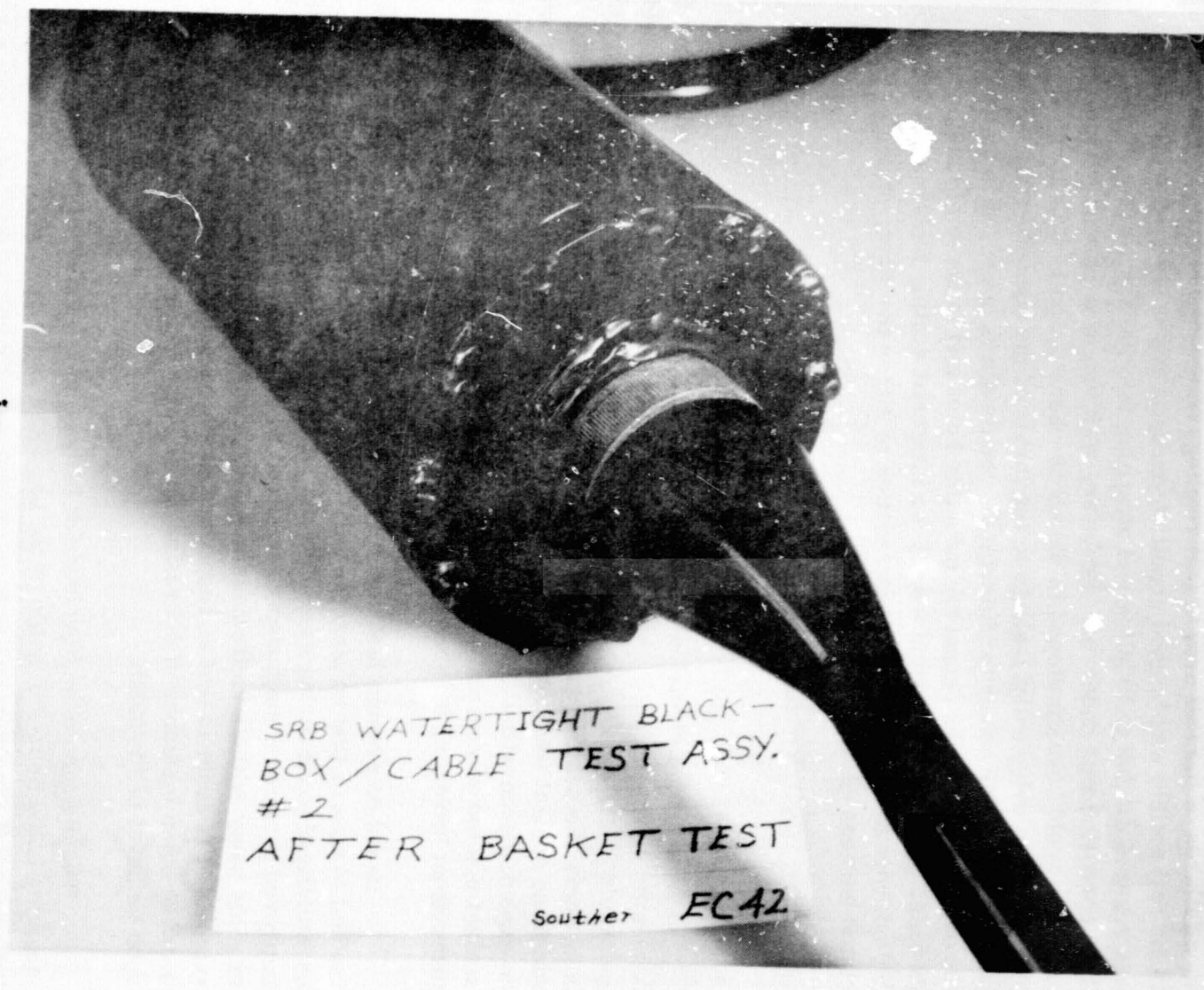
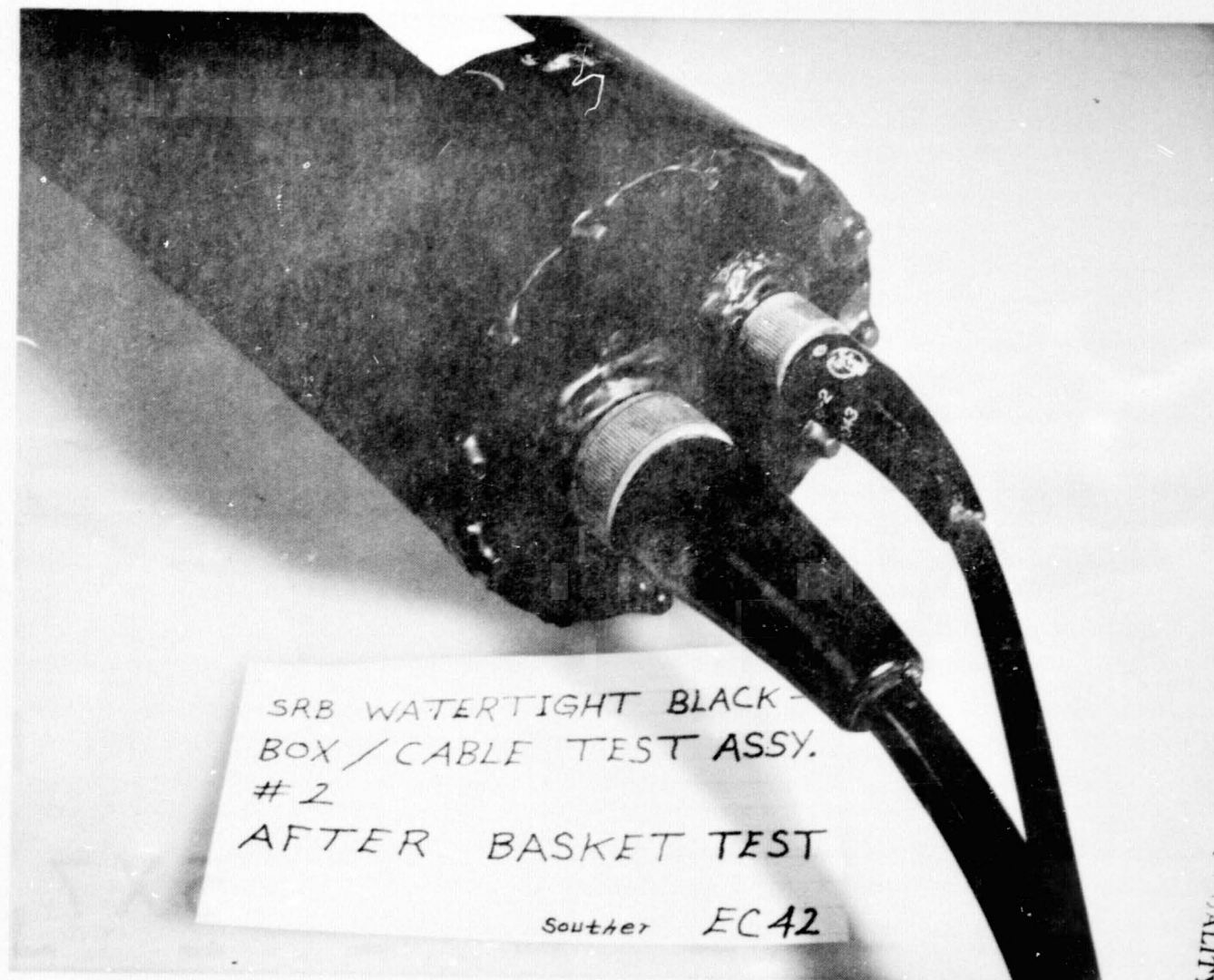


Figure 105. SRB watertight black box/cable test assembly No. 2 after basket test.

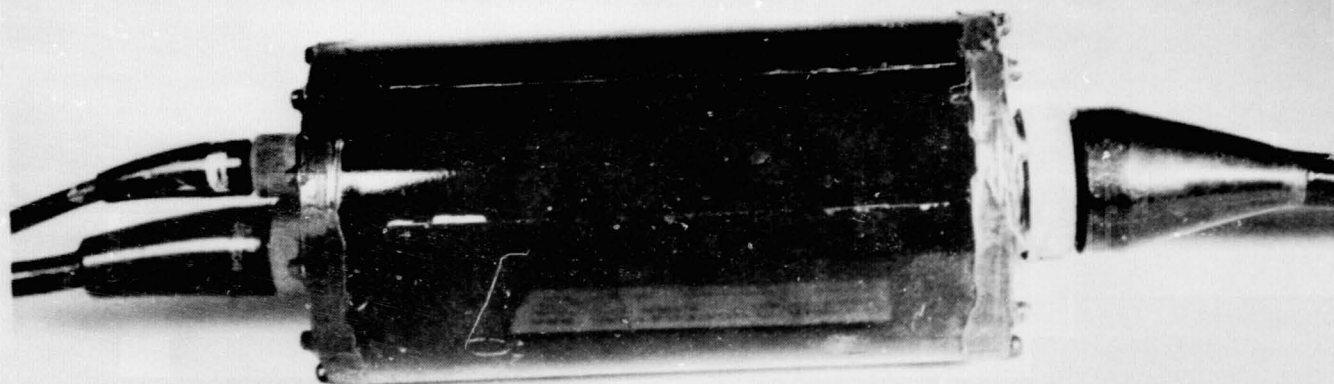


SRB WATERTIGHT BLACK-
BOX / CABLE TEST ASSY.
#2
AFTER BASKET TEST

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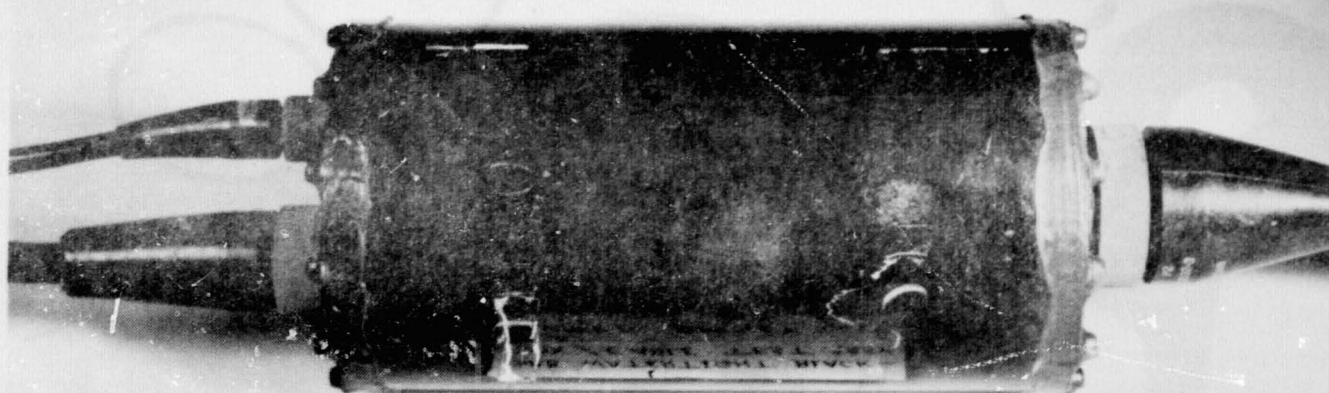
Figure 105. (Continued).



SRS WATER-TIGHT BOX / CABLE TEST ADAPTER
#2
AFTER PASSED 1

Figure 105. (Continued).

UNIT 102 (Continued)



ONE WATER-TIGHT BLACK
BOX / CABLE TEST ASSY.
#2
AFTER BASKET TEST

MILITARY FC42

Figure 105. (Continued).



Figure 105. (Continued).

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Figure 105. (Continued).

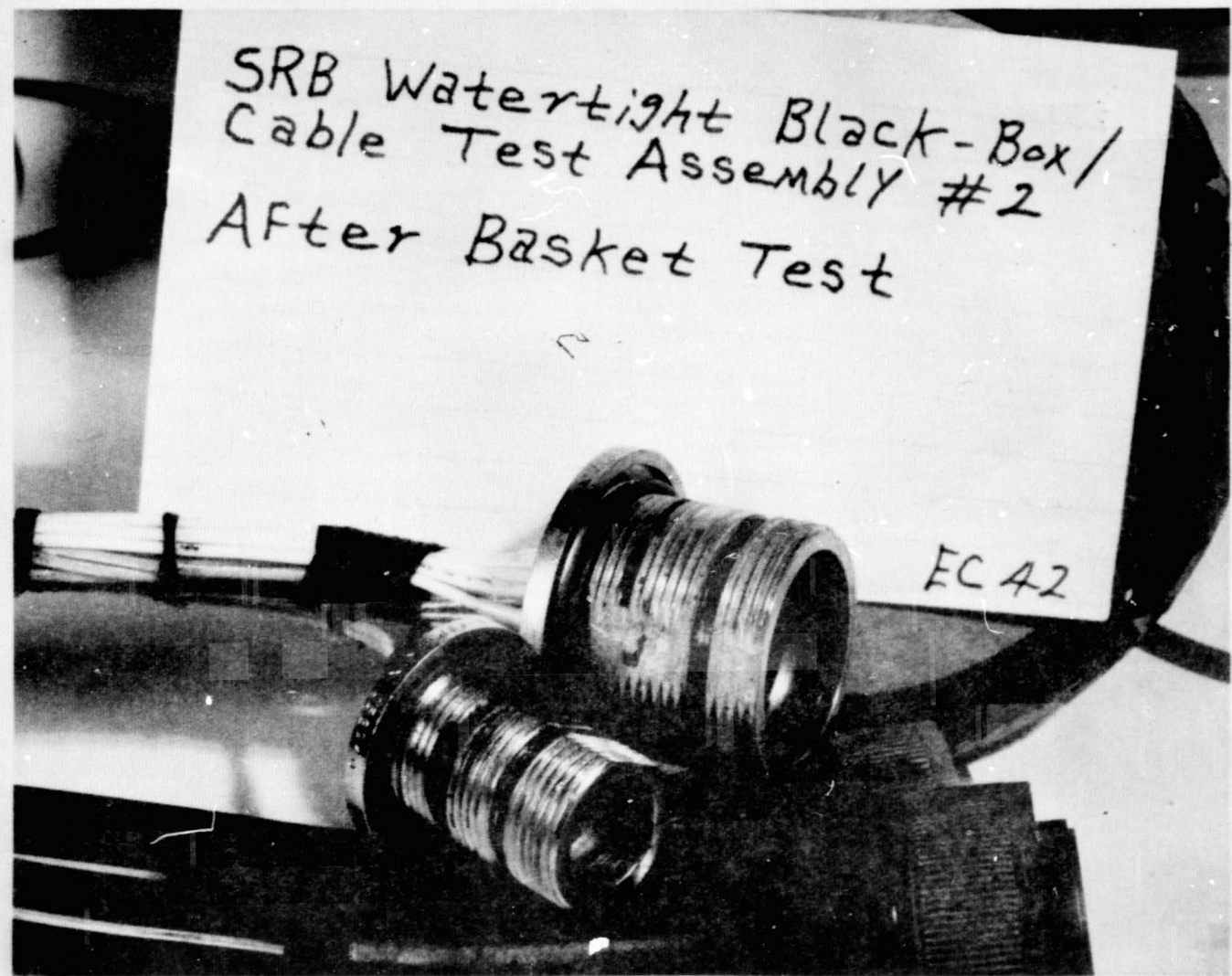
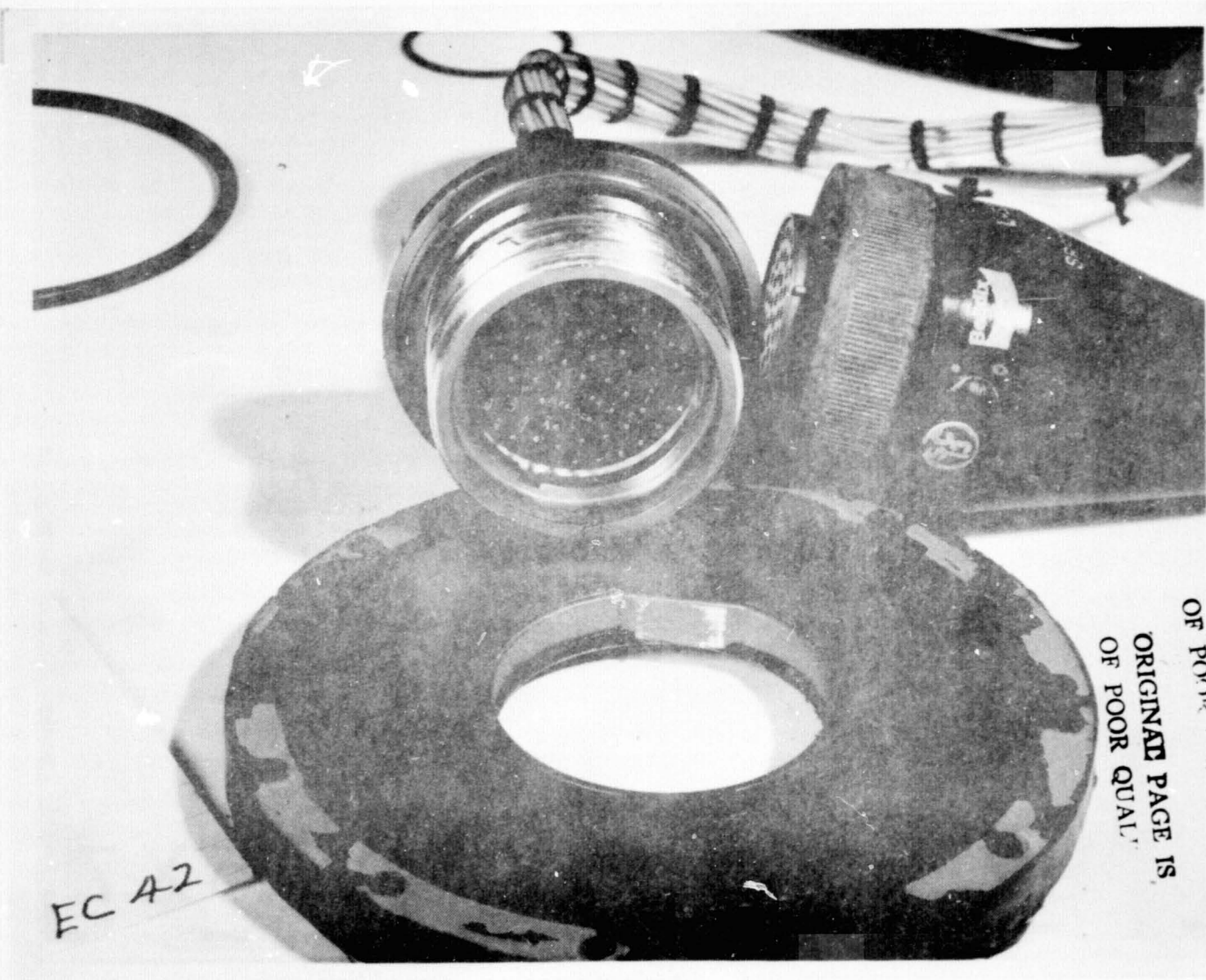


Figure 105. (Continued).



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Figure 105. (Continued).

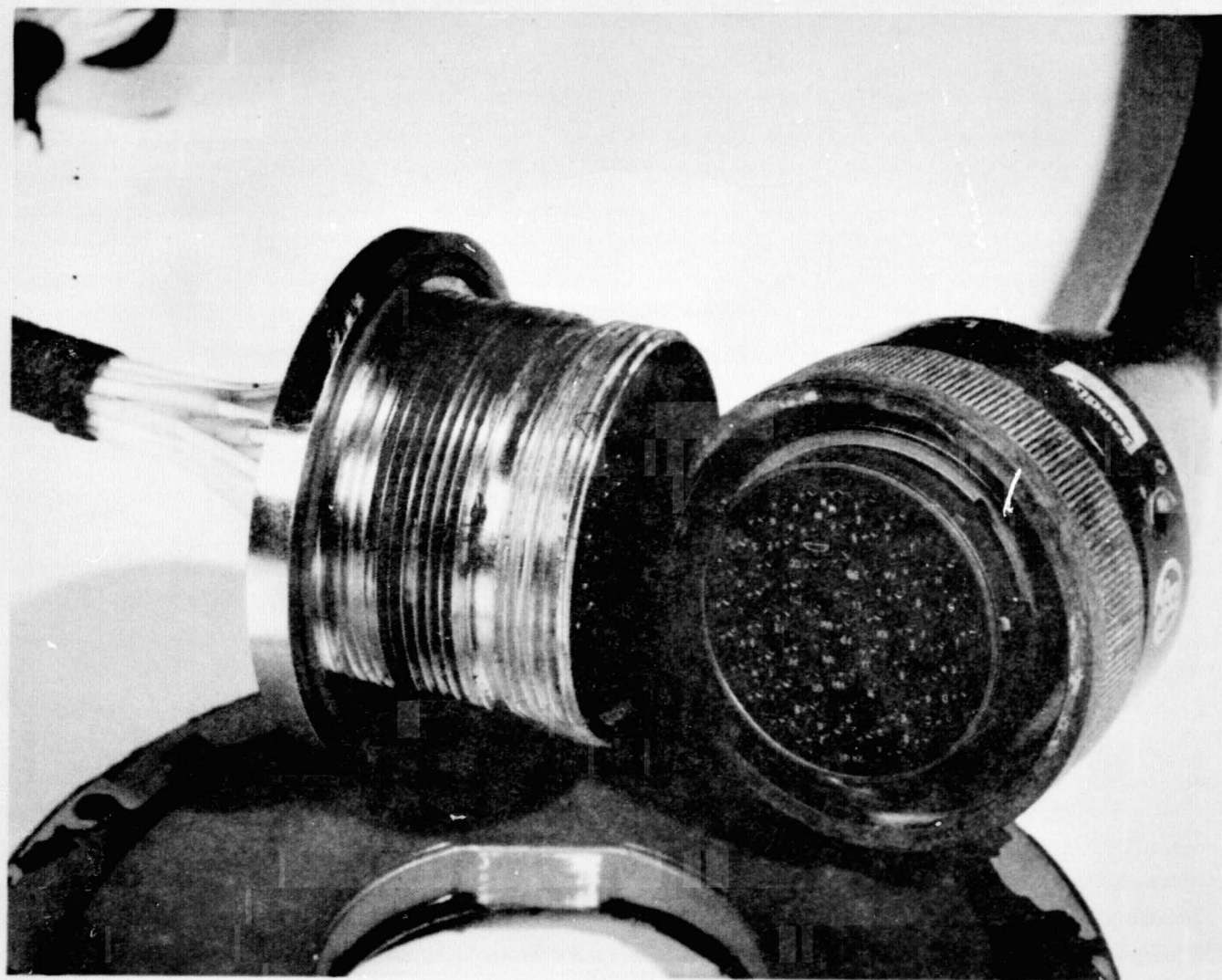


Figure 105. (Continued).

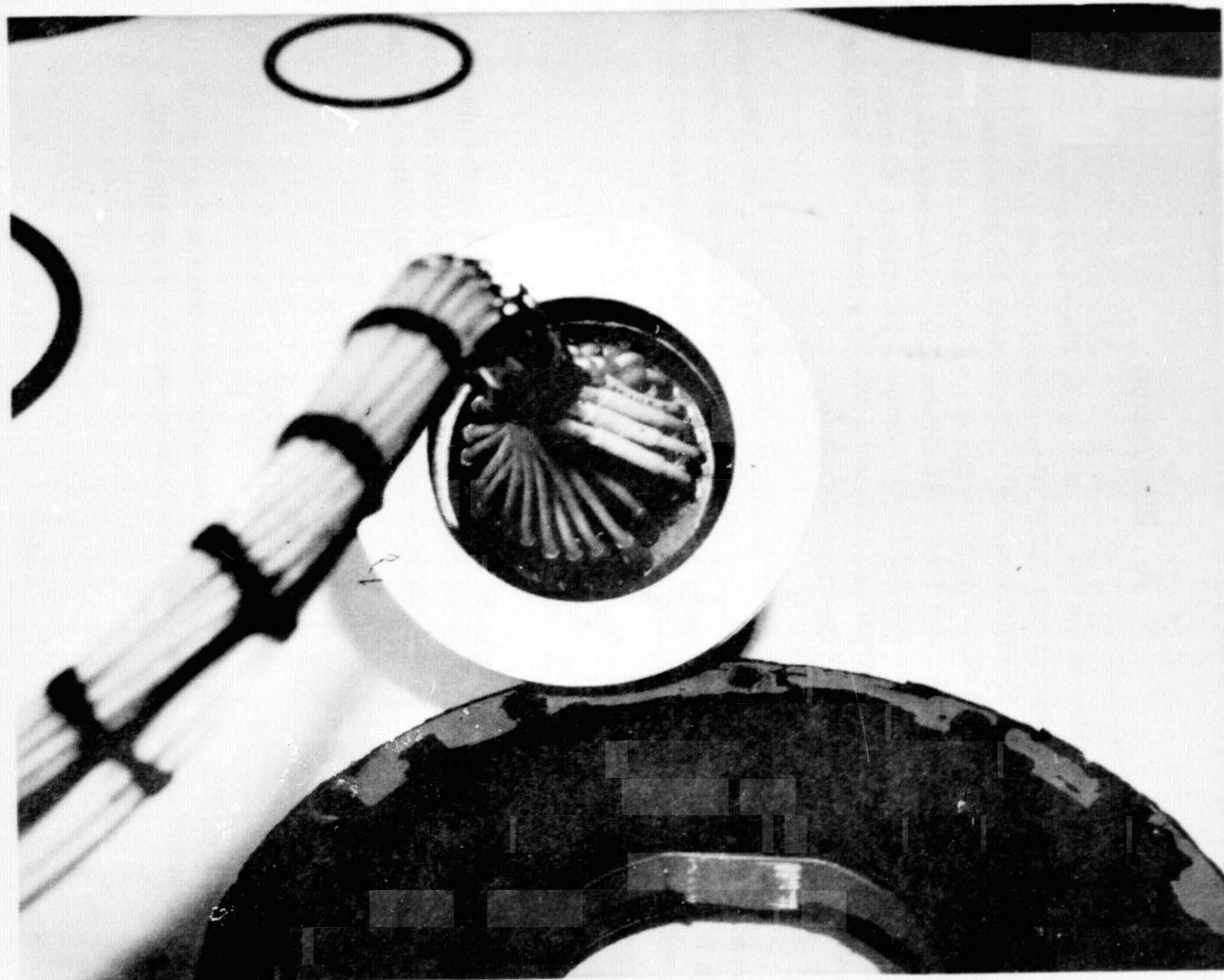


Figure 105. (Concluded).

XIII. CABLES

A. Discussion

The three cables on the ITB as part of the electrical subsystem were manufactured in accordance with MSFC Procedure 16A02981 (Cable Assemblies, Watertight, Reusable, Specification For). Conductors are polytetrafluoroethylene insulated, nickel-coated copper in accordance with 40M39513 (Wire, Electrical, Hook Up, General Specification For). The watertight connectors are in accordance with MSFC Procedure 16A02980 (Connectors, Electrical, Circular, Miniature, Underwater, Specification Control Drawing For). The molding and jacketing material is nonreverting polyurethane.

The cables used as part of the electrical subsystem on the ITB were reused in the basket test. Prior to reuse the outside of the cables were cleaned with tap water and a small brush. The cable connectors were cleaned with isopropyl alcohol and a small brush.

B. Assessment of Tests

The cables were subjected to the same test conditions as the black box described in Section XII.B with no electrical failures. Some mineral deposits, barnacles and discolorations were observed, but no significant damage to cable assemblies was noted.

C. Conclusions

Based on ITB and other testing, including the basket test program, it is believed that the watertight cable design is adequate for use on the SRB.

XIV. TVC COMPONENTS

A. Fluid Manifold

1. Discussion. The fluid manifold is a component of the SRB/TVC subsystem. It is a collector and distributor of subsystem hydraulic fluid, having line connection provisions to interface with a hydraulic reservoir, hydraulic pump, case drain, hydraulic actuators, and panel mounted service connections.

The fluid manifold consists of a machined housing fabricated from 304 CRES. This housing contains a number of drilled fluid passages which terminate at MS33656 threaded boss connections for attachment of fluid tubing and connectors. It also contains a high pressure relief valve and a low pressure relief valve. An internal steel mesh filter is included to remove contaminants from the fluid returned to the manifold from the pump case.

The hardware tested in the basket test is highly representative of the flight article. The only significant difference is that the test article contained an aluminum high pressure relief valve. Because of this, the valve was removed prior to the test, and the open port in the manifold was plugged with a threaded CRES plug. This item is fabricated from CRES for the flight article.

The only parts of the manifold that would be expected to corrode under the conditions of this test and/or flight conditions are the faying surfaces under each of the fittings. This type of corrosion is a very prevalent and serious form of corrosion on stainless steels in seawater, occurring in crevices, under the heads of fasteners, under gaskets, etc. The crevices in the manifold would be under the fittings. The corrosion is caused by the lack of oxygen in that area and the subsequent inability of the steel to repair itself.

The corrosion protection method to be used in this component is to prevent seawater entering these areas under the fittings which will be done by using sealants. In this test 7 sealants were applied to the 14 fittings (1 sealant for each 2 fittings). The following were used: (1) Zinc Chromate Putty, MIL-P-8116; (2) Corrosion Inhibiting Compound, MIL-C-19459; (3) Conoco HD Calcium Grease No. 1; (4) Conoco HD Calcium Grease No. 2; (5) Corrosive Preventive Compound, MIL-C-16173, Type 2; (6) Corrosive Preventive Compound, Type 3; and (7) Texaco Grease, AFB-2.

2. Assessment of Tests. There was no corrosion of the manifold as the result of the seawater exposure during the basket test. All sealants seem to have performed equally well in preventing seawater from entering the crevices.

3. Conclusion. It appears that this component can be adequately protected for the required missions if care is taken in the application of the sealant.

B. Auxiliary Power Unit

1. Discussion. The auxiliary power unit (APU) provides shaft power to drive the hydraulic pump of the SRB/TVC subsystem. The APU operates through catalytic breakdown of liquid hydrazine into hydrogen, nitrogen, and ammonia gases which are fed through a nozzle to spin a turbine. The turbine drives the hydraulic pump through a gear box.

The APU consists of a pump and control valves to supply and control hydrazine flow, a gas generator to catalytically decompose hydrazine, a turbine assembly to convert hydrazine energy into mechanical energy, and a gear box to transfer the mechanical energy to the hydraulic pump. The APU also has interconnecting lines, fittings, electrical connectors and fasteners, and is mounted in the SRB.

The hardware tested in the basket test consisted of the following:

- a. Gear Box Input Housing (A-356 aluminum, painted with two coats of epoxy primer)
- b. Gear Box Output Housing (2219-T852 aluminum, painted with two coats of epoxy primer)
- c. Generator Assembly (Hastelloy B)
- d. Exhaust Housing (cobalt alloy)
- e. Turbine Housing (cobalt alloy)

f. Gas Generator Valve Assembly (2024-T4 aluminum, painted with two coats of epoxy primer)

g. Vibratis Isolation System Cushions (304L stainless steel).

2. Assessment of Test. Visual examination of the APU parts indicated some rust spots in the Hastelloy B which appeared to come from weld splatter. The bolts (A286 steel) holding the exhaust housing had some rust on the heads.

3. Conclusions. It appears that this component can be adequately protected with a minimum amount of corrosion if care is exercised in protection of the system, i.e., sealants, coatings, paints, etc.

XV. CLEANING

A. Cleaning Technique Evaluated on ITB

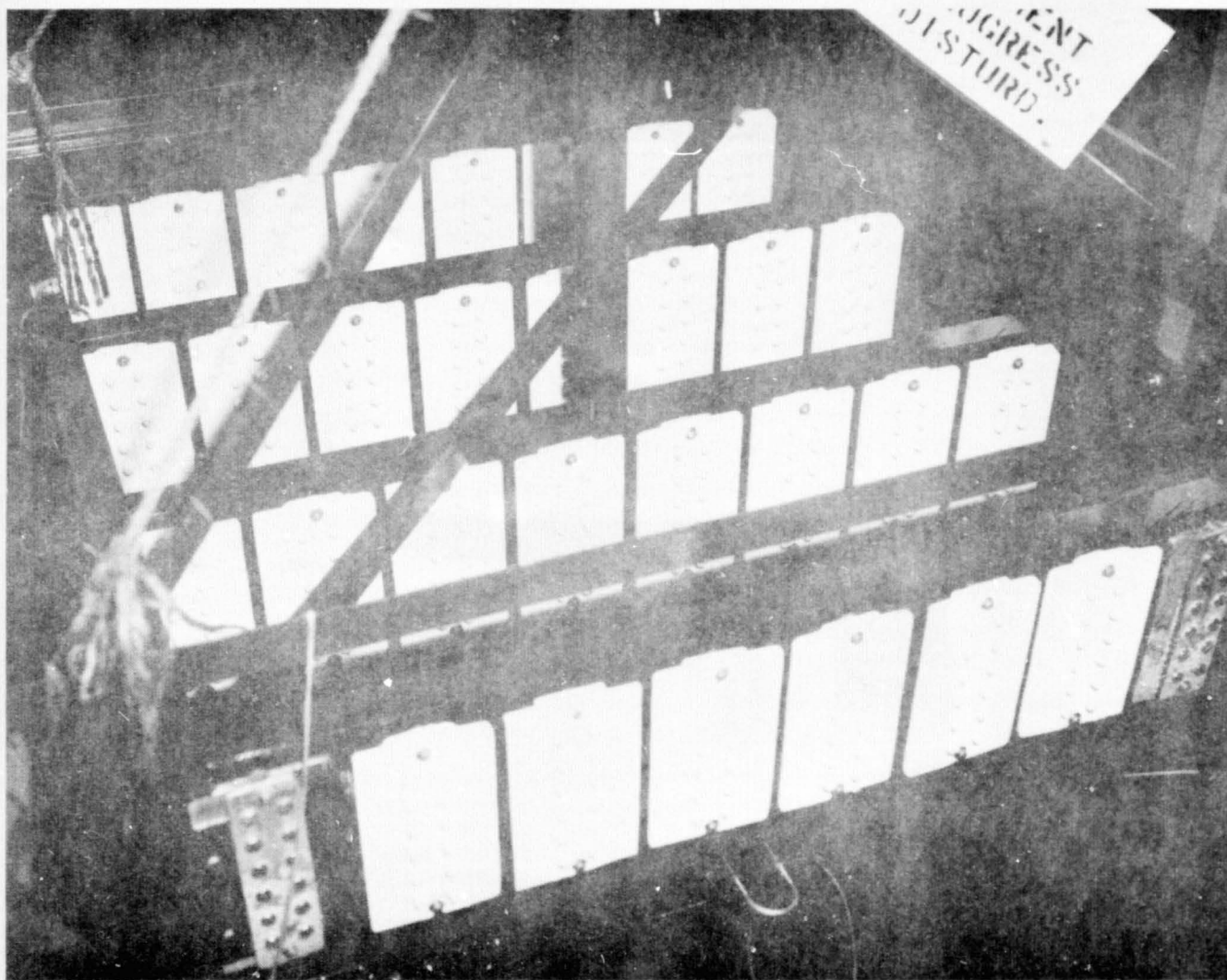
A cleaning procedure for SRB hardware was developed using small aluminum panels for test substrates (Fig. 106). Panel surfaces were contaminated in ways to simulate residue expected to accrue on SRB surfaces during launch and recovery operations; some panels were soiled with oily grime, others were exposed to artificial seawater, and others were immersed in the Atlantic Ocean and KSC harbor areas for periods of 10 to 20 days.

The objectives of the cleaning operations performed during refurbishment of the ITB were as follows:

1. Determine the test effectiveness of the cleaning procedure in removal of marine growth. ITB exposure to summer water resulted in a great deal more marine growth on surfaces than was observed on small aluminum test panels that were exposed during winter months.
2. Determine requirements for scrubbing or other mechanical action for removal of harbor silt and marine growth that was not present on small test panels.
3. Evaluate effectivity of the Orion selective ion meter in monitoring the cleaning process.
4. Evaluate effectivity of the final DI water rinse, in terms of chloride ion residue, on large hardware surfaces.

Although both sections of the ITB were thoroughly cleaned during the refurbishment cycle, the principal focus of ITB cleaning activities for assessment of the proposed SRB cleaning procedure was the aluminum assembly ("top" half) that presented a wide expanse of epoxy coated sidewall, free of TPS except for two small areas of bonded silicone and bonded cork.

After 7 days ocean exposure followed by 3 days in the Banana River, the ITB was heavily soiled, and marine growth (plant and animal) was present on painted metallic and nonmetallic surfaces. A comprehensive photographic recording of these post-recovery conditions was made after return of the ITB to MSFC (Figs. 107 and 108).



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Figure 106. Panels used to develop cleaning procedure.

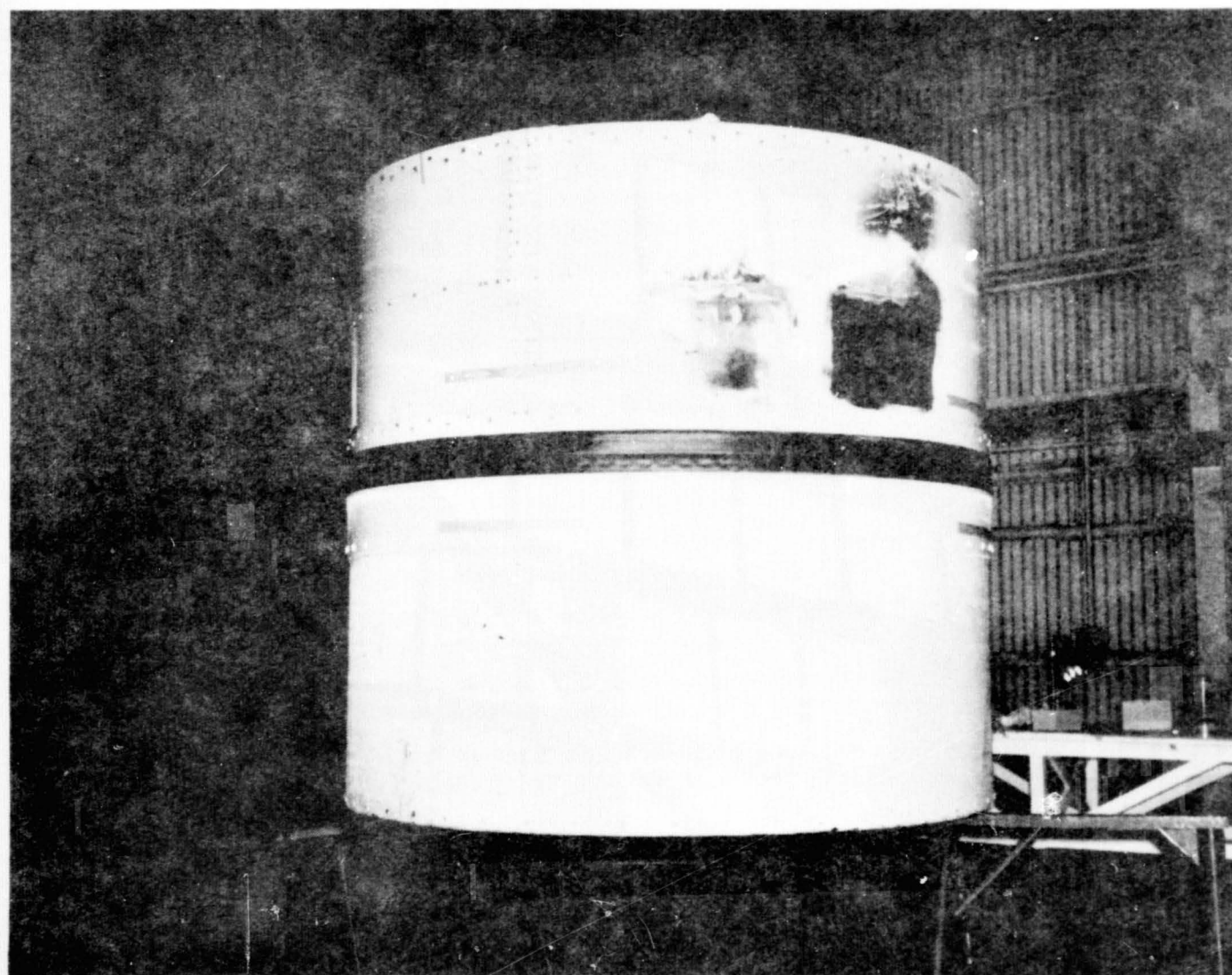
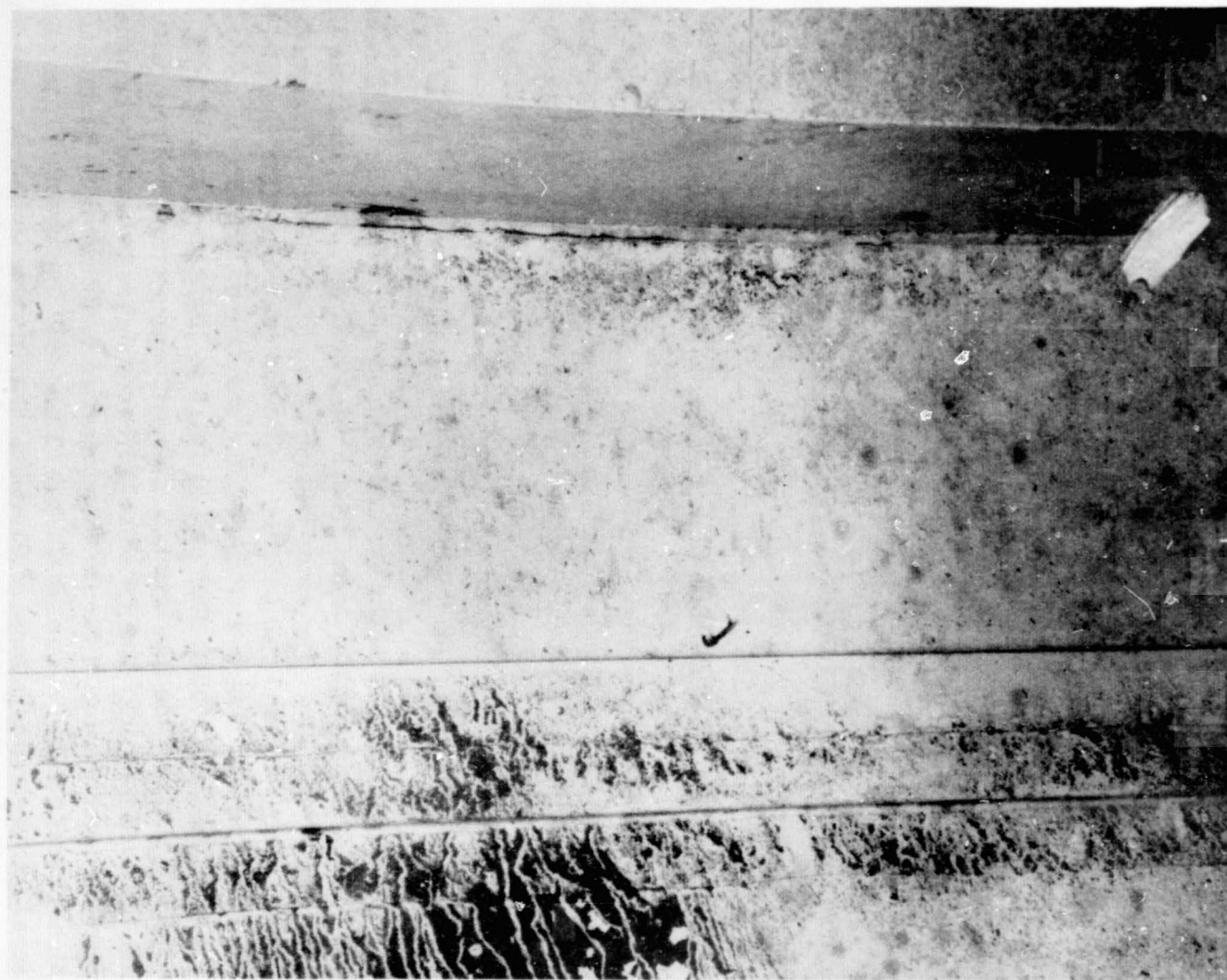


Figure 107. ITB at MSFC after KSC exposure.



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Figure 108. Interior of ITB showing typical heavily soiled area.

The standard SRB cleaning procedure as developed using aluminum test panels consists of:

1. Potable water rinse
2. High pressure 1378.96 kN/m^2 (200 psi) hot water 71.1°C (160°F) and detergent (Turco 5948)
3. High pressure hot water rinse (Fig. 109)
4. DI water rinse (ambient temperature).

High pressure hot water was obtained through a Sellers hydraulic cleaning unit (Fig. 110).

B. Assessment of Cleaning Effectiveness

Surface chloride readings were obtained at various stages of the cleaning process using the Orion chloride ion electrode system (Model No. 407A/96-17). While these readings cannot be directly correlated to chloride concentration per unit area, they are an indication of cleaning effectiveness. Initial readings taken before potable water rinse of the ITB on random spots wet with a wash bottle averaged greater than 1000 ppm chlorides.

Completion of the first three steps of the standard cleaning cycle removed the bulk of the visible contaminants. There was, however, a recognizable film remaining on the surface. The water laser was set to simulate the high pressure water 5515.84 kN/m^2 (800 psi) 757 liter/min (200 gpm) that KSC has selected to obtain cleaning action in lieu of mechanical scrubbers. Using a fan nozzle at 6.89 to 62 mN/m^2 (1000 to 9000 psi) at 101.6 to 304.8 mm (4 to 12 in.) from the ITB surface, the film was not removed; wiping with a wet sponge readily removed the film. The Orion selective ion meter indicated a residual chloride ion concentration of 200 to 300 ppm where visible residue remained and higher concentration near areas where "bleed out" was possible from faying surfaces. On areas where most of the visible detritus was removed, a reading of 30 to 70 ppm chlorides was obtained.

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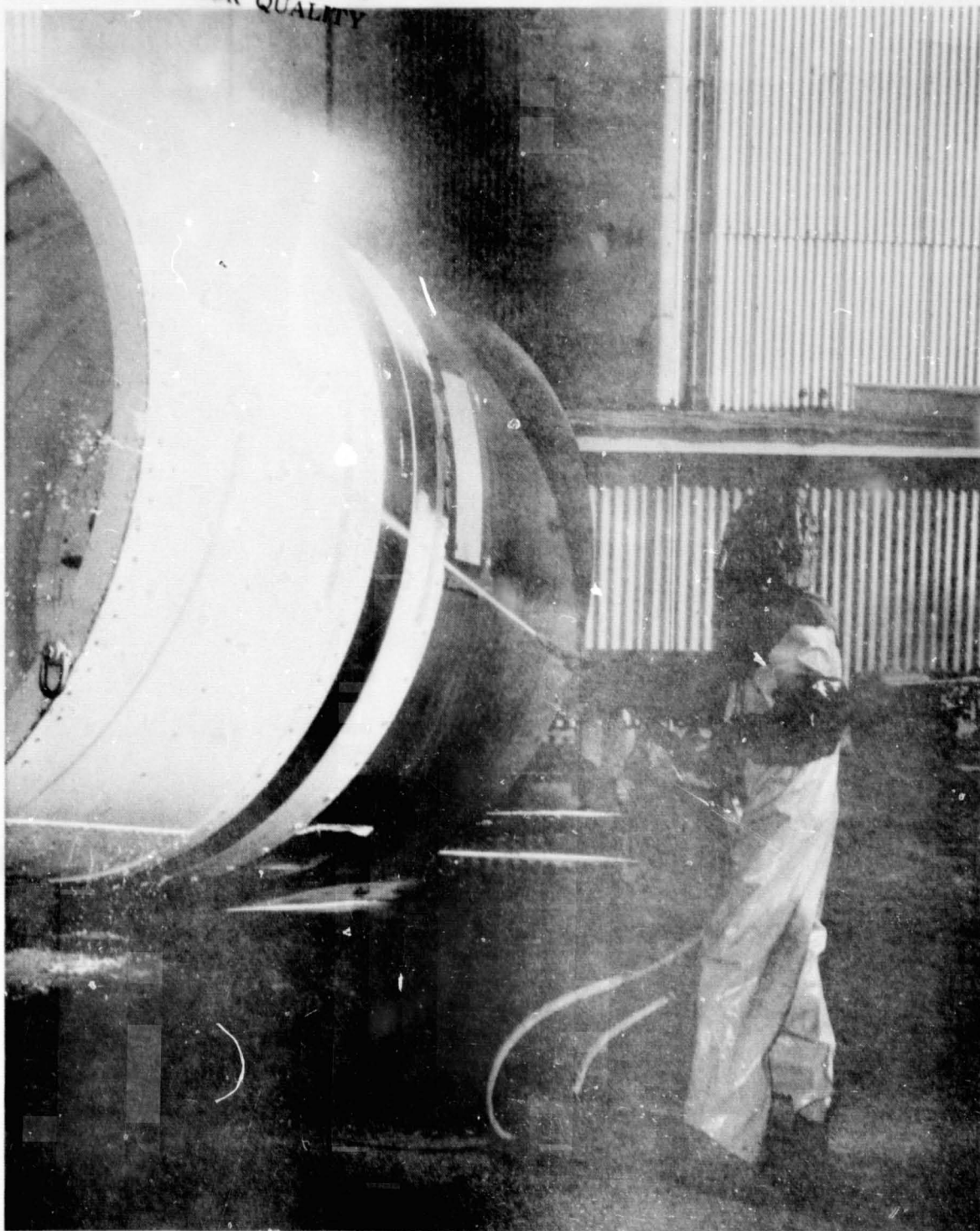


Figure 109. High pressure hot water rinse.

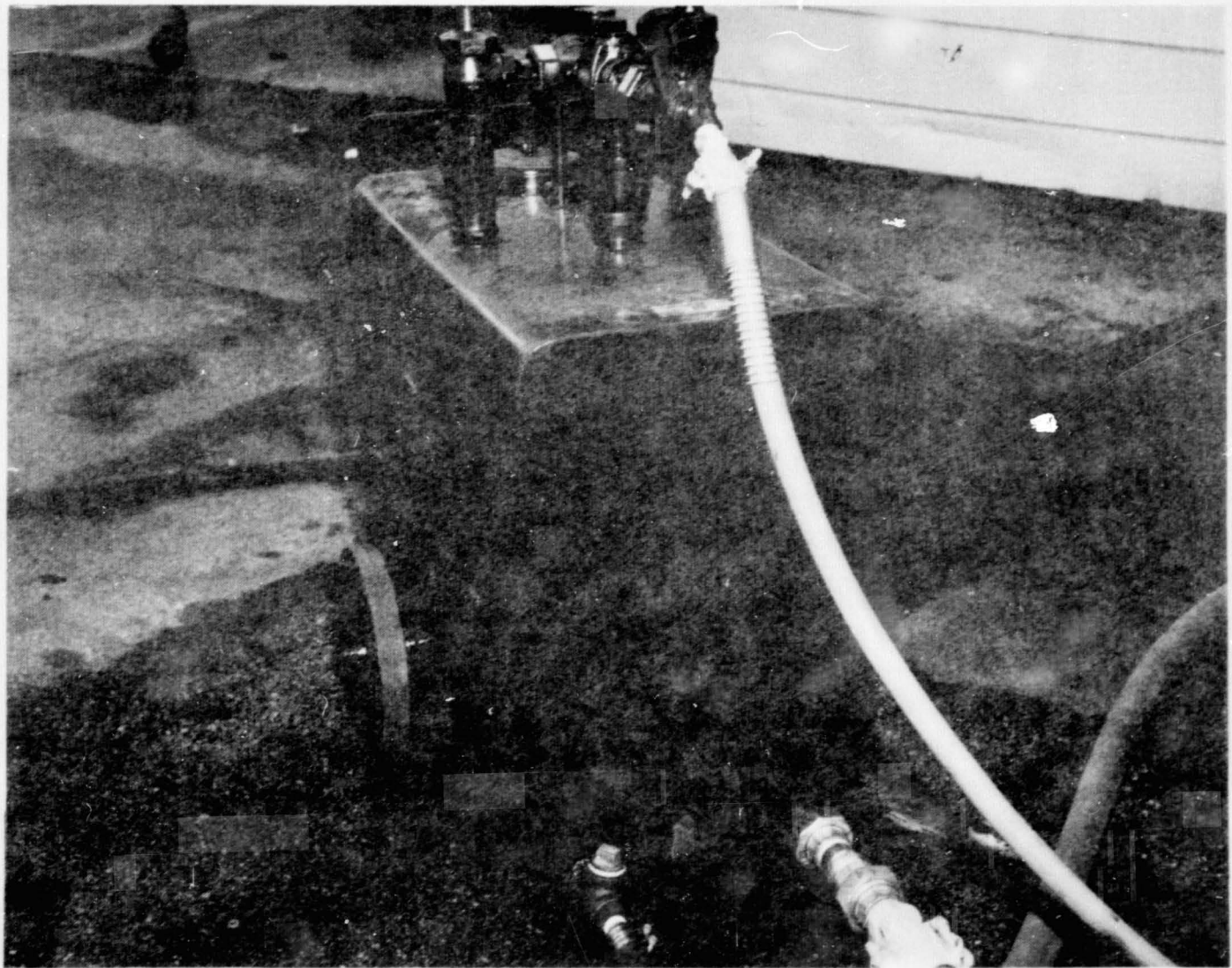


Figure 110. Sellers hydraulic jet unit.

The smoke residue on the painted surface above the MXSA that had been subjected to thermal cycling was not effectively removed by the detergent and/or high pressure spray. Mechanical action will be required for removal of this type residue.

After rinsing with DI water for approximately 5 min, the chloride ion concentration was below 10 ppm. To reaffirm that the Orion meter was responding to chloride ions present, a handprint was implaced on the surface of the ITB, and Orion reading in that area was shown to be 20 to 30 ppm; rerinsing the area with DI water dropped the chloride ion concentration off scale again (less than 10 ppm).

C. Conclusions

An overall evaluation of the proposed SRB cleaning procedure, based on the ITB experience, supports the following points:

1. The procedure appears effective in removing most visible surface contaminants and sodium chloride residue.
2. The Orion selective ion meter, when used after successive stages of the cleaning procedure to provide beginning-to-end values for relative chloride ion concentration, is a satisfactory approach to monitoring the cleaning process.
3. A residue film, similar to that obtained on an automobile when driving it in wet weather, remains on the painted metallic surface when cleaning is completed. This film is resistant to high pressure water impingement, and if its removal is desired, mechanical actions will be required.
4. Smoke residue deposited on painted surfaces by charring of adjacent insulated areas will likewise require some type of mechanical action for removal.
5. The final DI water rinse significantly lowers the chloride ion concentration on cleaned surfaces. This step should be continued as part of the SRB cleaning procedure.

XVI. REFURBISHMENT

A. Refurbishment Techniques

These operations include all major activities necessary to prepare the ITB for reapplication of MSA-1 prior to shipment to KSC for the second environmental exposure. These activities include:

1. TPS removal
2. Paint refurbishment
3. Sealant refurbishment
4. Clevis joint seal refurbishment.

B. TPS Removal

Removal of TPS (MSA-1) from the lower half of the ITB was accomplished with the water laser at a pressure of 68.95 mN/m^2 (10 000 psi) with an output of approximately 15.14 liter/min (4 gal/pm). The effective stripping rate was 0.0557 to $0.0753 \text{ m}^2/\text{min}$ (0.6 to $0.8 \text{ ft}^2/\text{min}$). The acreage of TPS on each SRB unit is estimated at 106.83 m^2 (1150 ft^2). A 0.914 m (3 ft) long by 0.228 mm (9 in.) wide section of scorched MSA-1 was mechanically masked and retained intact for MSA-1 refurbishment development studies.

One flat panel 762 by 152.4 mm (30 × 30 in.) of MSA-1 coated with Turco 6109 topcoat was also stripped with the laser. The Turco 6109 material toughness slowed the removal rate very little. The size of TPS being removed ranged from $152.4 \times 152.4 \text{ mm}$ (6 in.²) to microballoon sized particulates.

The properly cured coalescing agent on the test panel resulted in clean removal of the TPS system, including the coalescing agent, down to the epoxy paint substrate. The coalescing agent had overcured on the ITB and was not removed by the water laser. (The cure cycle for the coalescing agent on large components is difficult to extrapolate from experience with small samples.) Coalescing agent was removed from approximately one-half the covered area using Cee Bee A-202 chemical stripper, which also removed the epoxy paint

and primer down to the bare metal substrate. Coalescing agent was retained on the remainder of the covered surface for future evaluation of MSA-1 application methods over fully cured coalescing agent.

A MSA-1 backup removal system (chemical) was evaluated for possible laser inaccessible areas or where small areas need to be stripped for hardware removal, rework, etc. Prior to water laser removal of the MSA-1, an area of approximately 1 ft² was selected on the ITB, the topcoat was sanded off and a liberal coating of Turco 6015 stripper was applied to the area. The MSA-1 was approximately 5.08 mm (0.200 in.) thick; penetration of the MSA-1 required approximately 20 min. A plexiglass scraper easily removed the MSA-1. Test of additional time (up to 1 h) did little to add to the softening effects on the MSA-1 beyond the adequate 20 min time interval. The 6015 stripper was selectively developed to remove the MSA-1 without adversely affecting the epoxy paint system.

The two small areas of silicone bonded cork and silicone bonded PD200 on the upper half of the ITB were also removed with the water laser. The silicone adhesive in these test areas remained on the side wall after this treatment, but was effectively removed by Turco 6045 stripper without damaging the underlying paint.

C. Paint and Sealant Refurbishment

During cleaning operations on the mechanically fastened sections of the ITB, the Dow Corning 93-076 silicone sealant was lost from approximately 40 percent of the fasteners. Sealant was removed from the remainder of the fasteners, and all were completely cleaned and sanded in preparation for reapplication of DC-93-076.

Small pits of corrosion on the inside walls beneath the epoxy paint and primer were located. Those areas were concealed by small paint blisters approximately 6.35 mm (1/4 in.) diameter that were elevated so slightly above the general paint surface as to be not easily detectable. All spots of this type were sanded down to bare metal, feather-edged, and conversion coated in preparation for local reapplication of epoxy primer and paint.

Corroded areas where paint was damaged by handling or peeled off when the flotation was removed were also sanded down to bare metal, feather-edged, and conversion coated prior to spot application of epoxy primer and paint. As expected, spot paint repair has resulted in uneven coloration on the ITB side-wall. The original coating in areas not repaired is distinctly yellowed by comparison with the new paint. Primer and paint were also reapplied to those areas of the ITB where chemical stripping of the coalescing agent resulted in exposure of bare metal.

An estimated 60 manhours were expended on sealant/paint refurbishment. While no direct extrapolation from this single test item to SRB flight hardware can be made, the magnitude of this effort indicates that sealant/paint refurbishment can impact significantly the overall SRB refurbishment timelines.

D. Conclusions

The entire refurbishment operation should not be underestimated in its complexity and in the time required to accomplish the necessary tasks. The ITB was the first large piece of hardware on which disparate refurbishment requirements were integrated into a total system. Time and manpower requirements exceeded expectations, and careful attention is needed to this phase.

XVII. HANDLING

A. Handling Damage

During the first exposure and recovery of the ITB at KSC, handling damage was considerable. This damage was primarily caused by allowing the steel chains to abrade against the side of the structure. The resulting damage caused breaking and marking on the surface of the TPS coating material. In some cases, chunks of the TPS material were broken off (Figs. 111, 112, and 113).

During the summer of 1977 basket test program, materials samples were not subjected to normal handling practices due to the fact that basket and racks were utilized as a test vehicle rather than the ITB used in the 1976 test program. However, under these favorable conditions there were incidences wherein chips of painted surfaces occurred and scratches on the TPS coated surfaces were noted.

B. Conclusions

The SRB should be removed from the water by lifting in a horizontal position and placing it on a dolly or transport vehicle in this position. Extra care should be taken to insure that unit is not hit by any object that could cause damage.

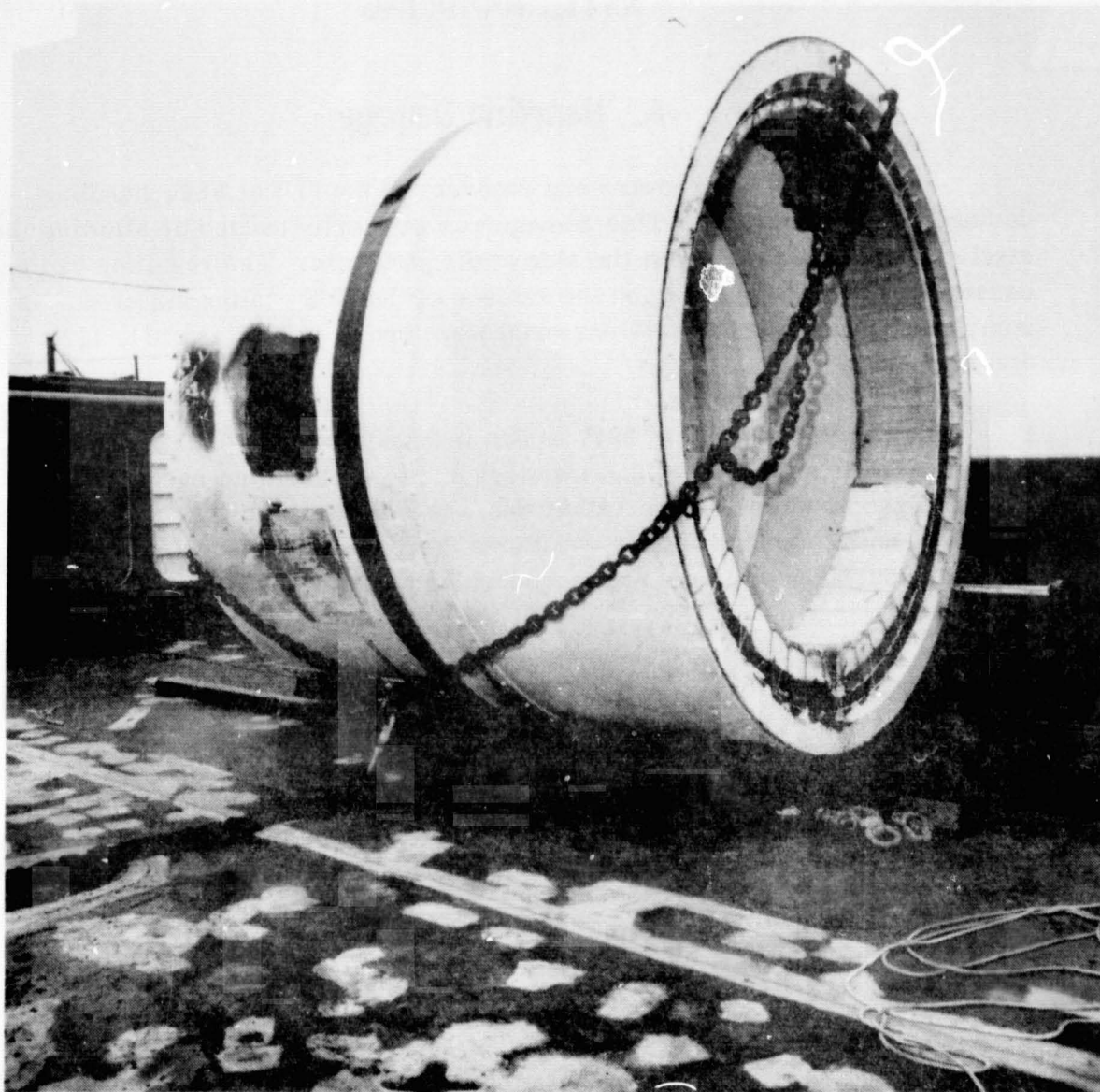


Figure 111. ITB aboard ship prior to beginning test cycle (note heavy chains in contact with protected surface).

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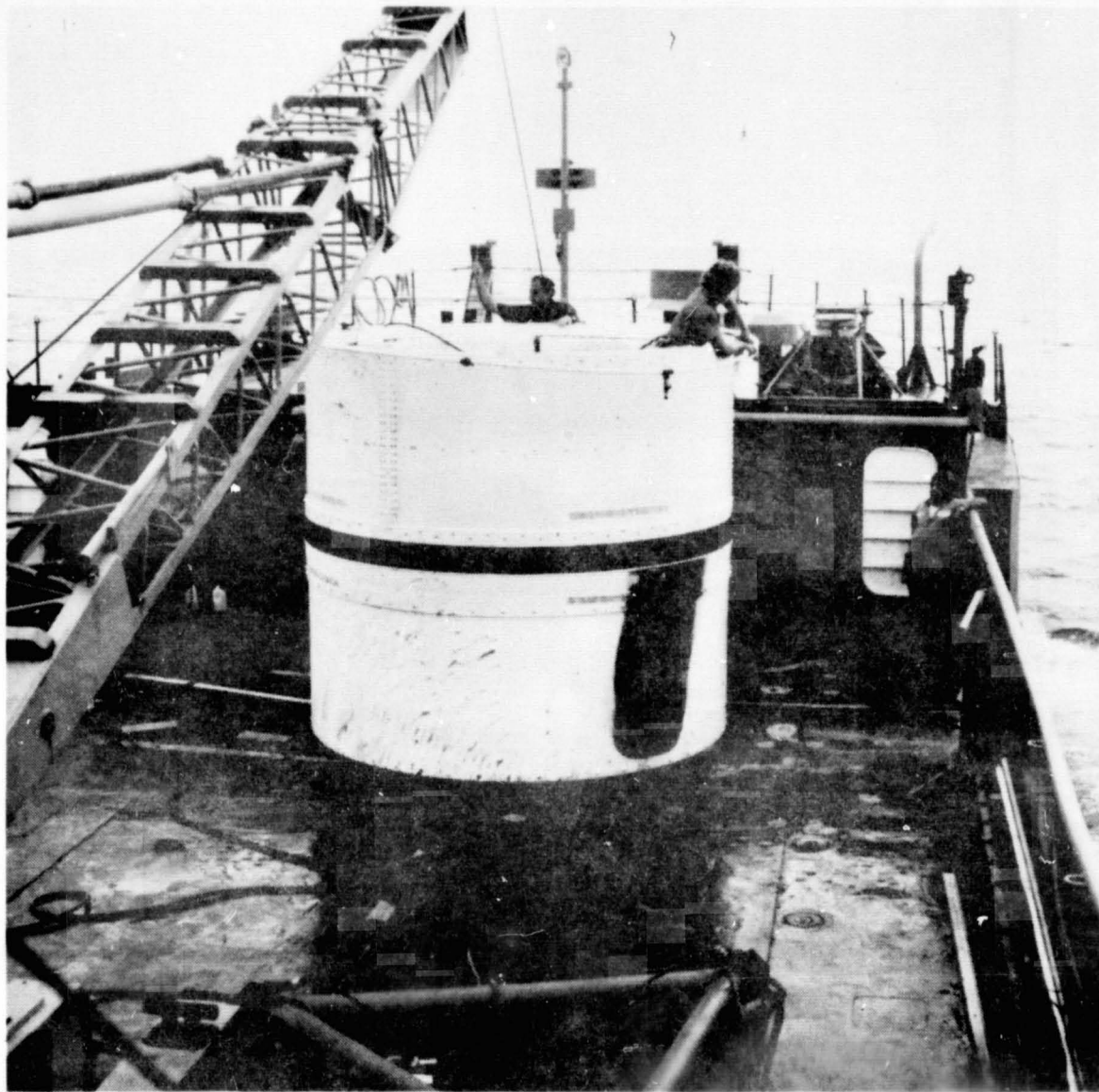


Figure 112. ITB aboard ship prior to towing.

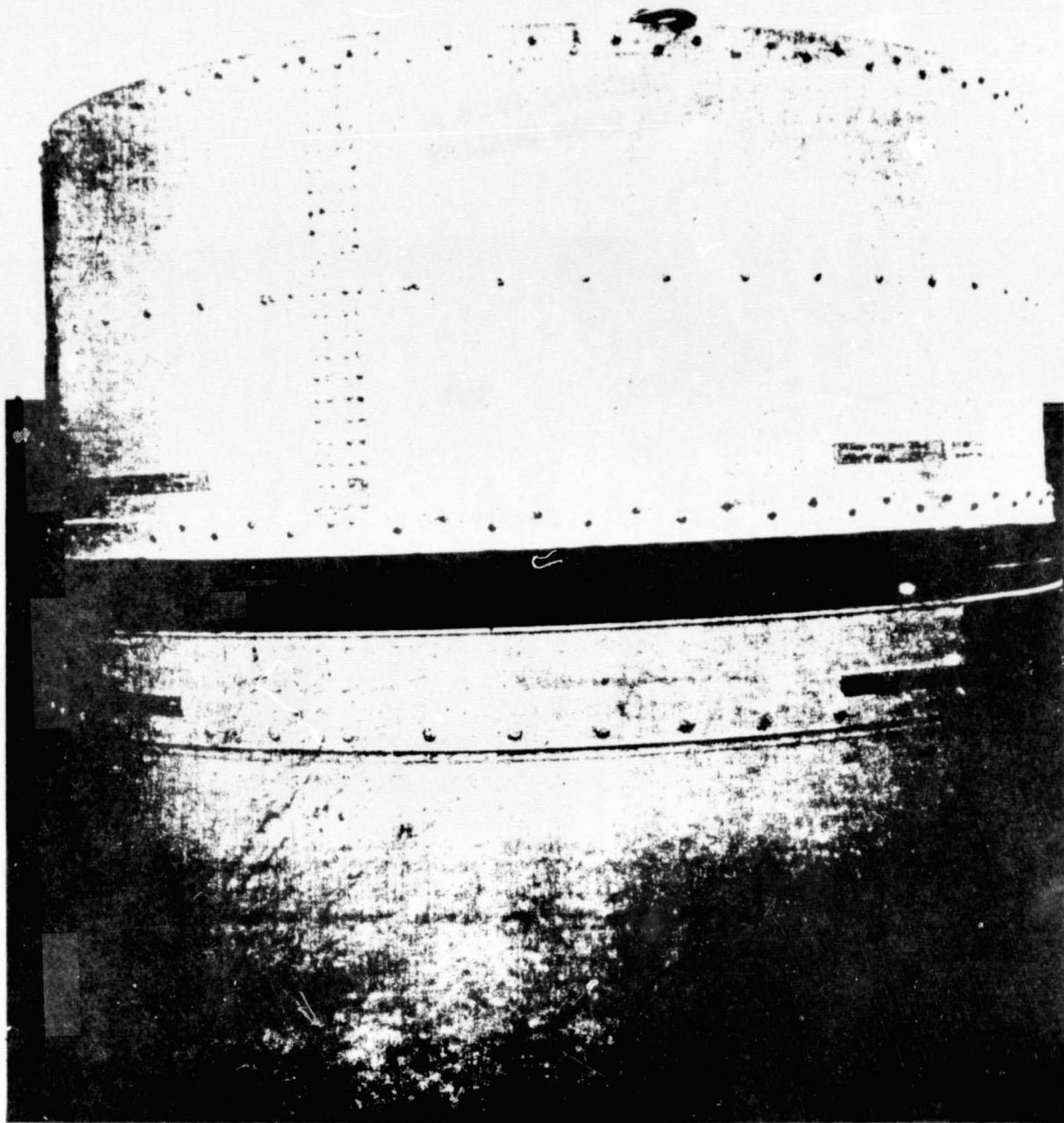
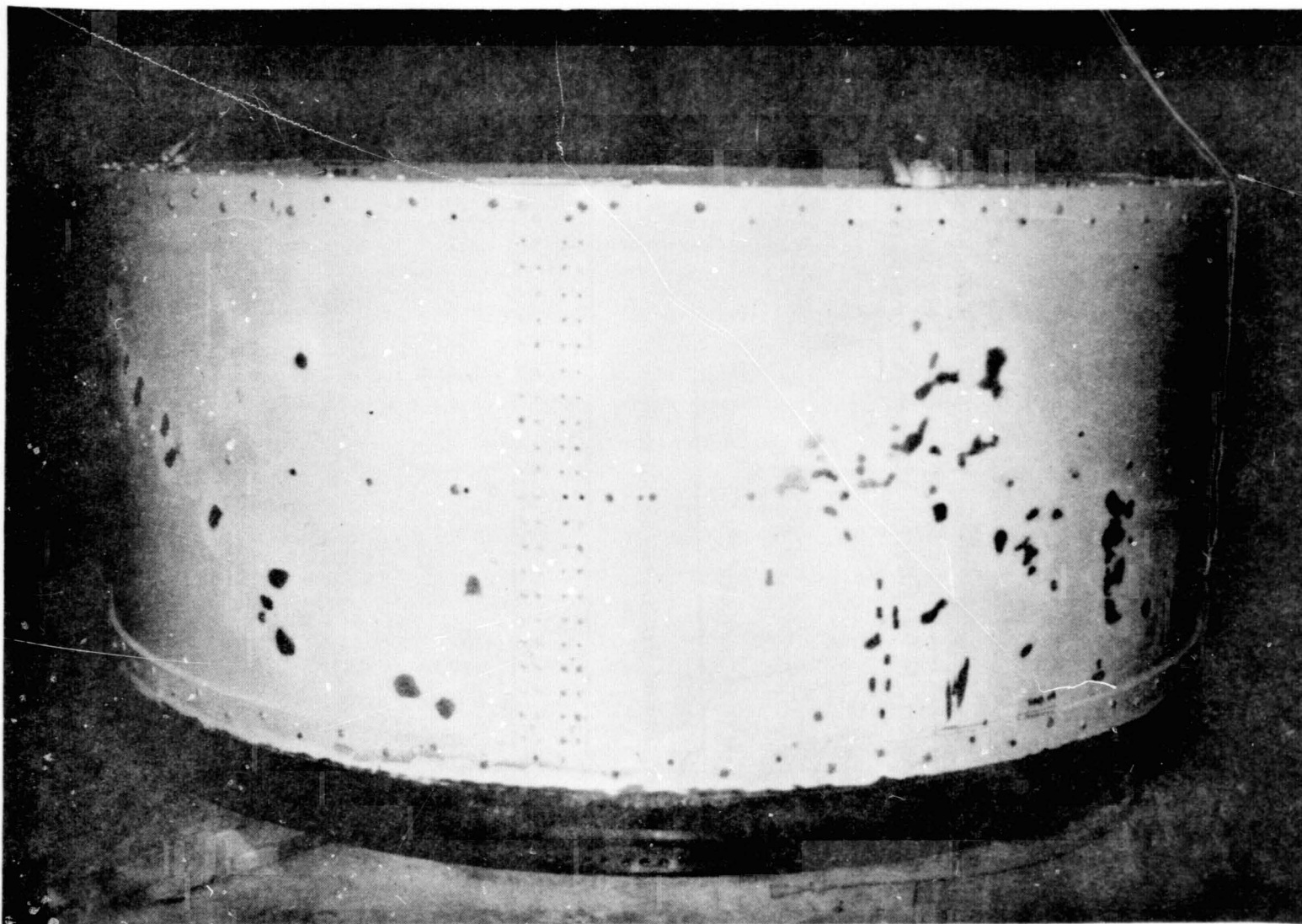


Figure 112. (Concluded).

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Figure 113. Upper portion of ITB in paint shop undergoing paint touch-up. (Areas of chipped or damaged paint have been locally sanded.)